VOLUME 21 APRIL, 1933 NUMBER 4

PROCEEDINGS
of
The Institute of Radio Engineers

Eighth Annual Convention
Chicago, Illinois
June 26, 27, 28, 1933

Form for Change of Mailing Address or Business Title on Page XIX

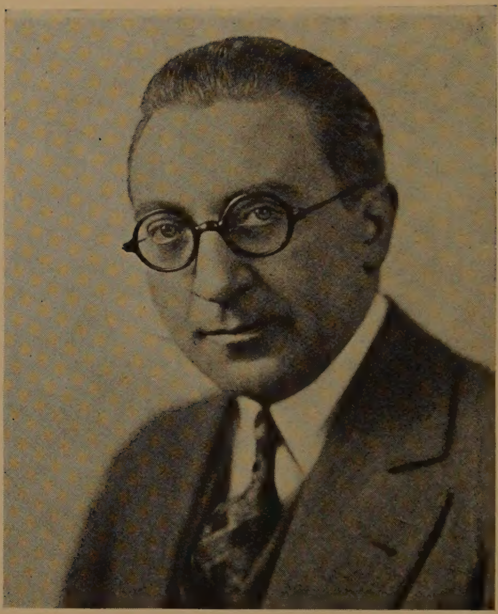
Institute of Radio Engineers Forthcoming Meetings

CONNECTICUT VALLEY SECTION
April 20, 1933

NEW YORK MEETING
April 5, 1933
May 3, 1933

SAN FRANCISCO SECTION
April 19, 1933

WASHINGTON SECTION
April 13, 1933



FREDERICK A. KOLSTER, DIRECTOR, 1933

Frederick A. Kolster was born in Geneva, Switzerland, on January 13, 1883. He attended public school in New England, and in 1908 graduated from Harvard University. During the six years prior to his graduation he acted as assistant to John Stone Stone. From 1909 to 1911 he was assistant to Lee deForest, and from 1911 to 1912 he assisted Fritz Lowenstein.

He then became chief of the Radio Section of the U. S. Bureau of Standards, which position he held until 1921 when he became associated with the Federal Telegraph Company. At present, he is a radio consultant for the International Telephone and Telegraph Company.

Among his important developments of radio devices and systems will be found the Kolster decremeter and the Kolster radio compass. He initiated the radio beacon system operated under the U. S. Bureau of Lighthouses, and was a technical advisor to the U. S. Delegation to the International Radio Conference held in London in 1912.

He became an Associate member of the Institute in 1912, a Member in 1913, and a Fellow in 1916.

March Meeting of the Board of Directors

A meeting of the Board of Directors of the Institute was held on March 1 at the Institute office. Due to the absence of Dr. Hull, the meeting was presided over by Melville Eastham, treasurer; the others present were M. C. Batsel, O. H. Caldwell, Alfred N. Goldsmith, R. A. Heising, J. V. L. Hogan, C. W. Horn, C. M. Jansky, Jr., E. L. Nelson, E. R. Shute, A. F. Van Dyck, William Wilson, and H. P. Westman, secretary.

Twenty-five applications for the Associate grade, one application for the Junior grade, and sixteen applications for the Student grade of membership were approved.

The proper notice having been forwarded to all Board members, three Sections of the By-Laws were amended to read as follows:

> Section 22—Unless otherwise ordered by the Board of Directors, meetings of the Board of Directors shall be held the first Wednesday of each month in the office of the Institute in New York City except that in July and August meetings may be omitted.
>
> Minutes of all meetings of the Board of Directors shall be sent to each member of the Board of Directors.
>
> Section 23—Unless otherwise ordered by the Board of Directors, meetings shall be held by the Institute on the first Wednesday of each month except July and August and at such other times and places as the Board of Directors may elect.
>
> Section 65—Unless otherwise ordered by the Board of Directors, an alphabetical and geographical list of members shall be published annually. The grade of each member shall be indicated in either list, or both, by a difference in type or otherwise, at the secretary's discretion. This list, usually in the form of a YEAR BOOK, shall be sent to all members without charge. The list of members shall be corrected to January 1st and mailed as soon thereafter as possible.

Following the amendment of the By-Laws, official actions were taken to dispense with the publication of the YEAR BOOK for 1933 and the June New York meeting.

The dates of June 26, 27, and 28, 1933 were established for the Eighth Annual Convention of the Institute to be held in Chicago, Illinois, with headquarters at the Hotel Sherman.

The report of the auditor covering an examination of the Institute's books for the fiscal year ending December 31, 1932, was accepted, and the balance sheet from this report will be found in the Report of the Secretary appearing elsewhere in this issue.

REPORT OF THE SECRETARY
INSTITUTE OF RADIO ENGINEERS
1932

SO THE membership may be informed of the more important details of Institute operations during the past year, this report is submitted. Although the report is written by the Secretary, his are the duties of a clearing agent to digest and collate numerous reports and actions of the Board of Directors, the many Institute committees, its sections, and secretarial organization.

General

At the close of 1932, the active membership of the Institute totaled 6403 as compared with 6734 at the end of 1931, a reduction of approximately five per cent. This is the first year in which the membership has shown a decline from the preceding year. However, conditions within the industry disclose evident reasons for a reduction in membership.

Institute sections, which number seventeen, have continued their regular meetings, and while the reduction in total membership is reflected in their affairs, no substantial damage appears to have resulted. Sixty meetings were held by the various committees in addition to the large amount of work accomplished through correspondence. The Papers Committee and Board of Editors in particular carry on their important and extensive labors practically entirely through correspondence.

The number of editorial pages published in the PROCEEDINGS has decreased by about twelve per cent from the 1931 figure. This reduction has been due to financial limitations.

A comparative balance sheet at the end of this report shows a net loss in operation for 1932. However, this loss is not a dangerously large proportion of the Institute's reserves which have been accumulated throughout the past years for use during contingencies such as exist at present.

Board of Directors

The Board of Directors is the governing body of the Institute, and during 1932 held ten regular meetings. There are seventeen members of the Board and the average attendance at each meeting was twelve.

Annual Convention

The Pittsburgh Section sponsored the seventh annual convention of the Institute which was known as the Twentieth Anniversary Convention in commemoration of the founding of the Institute in 1912.

This meeting, at which four hundred and sixty were present, was held on April 7, 8, and 9, at the Hotel William Penn, and, as in the past, included, in addition to organized inspection trips and the presentation of technical papers, an exhibition of component parts and engineering aids. The membership owes Chairman J. G. Allen and the Convention Committee which served under him a vote of thanks for their excellent efforts in the preparations for this convention.

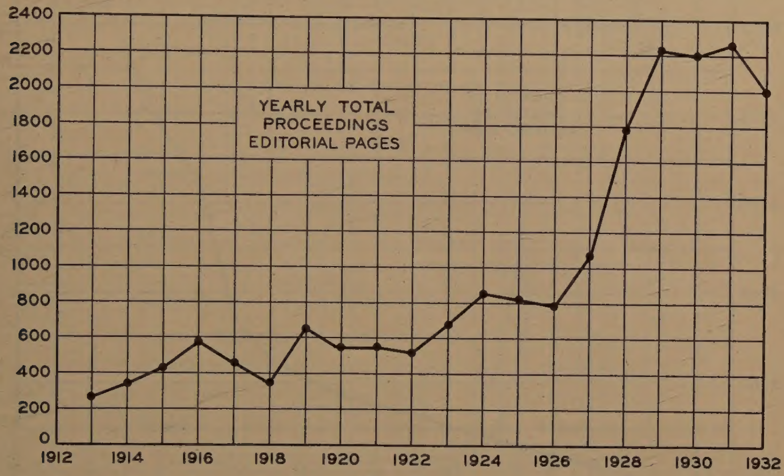


Fig. 1

Rochester Fall Meeting

November 14 and 15 were the dates for the 1932 Rochester Fall Meeting which was attended by almost two hundred. Ten technical papers comprised the backbone of the meeting, and group luncheons and dinners were so arranged as to permit almost every minute to be used to advantage. Virgil M. Graham and the committee over which he presided did an excellent job, and the appreciation of those in attendance was evident.

New York Meetings

Nine meetings of the Institute were held in New York during the year and permitted the presentation of seventeen technical papers. The average attendance was over three hundred.

Committees

A substantial portion of Institute work is carried on through the efforts of committees, either temporary or regular. These committees report to the Board of Directors and receive instructions from that

body. In some cases, the committee reports are of a purely advisory nature. As the decisions of these committees and the Board of Directors determines the policies under which the Institute operates, their importance is evident.

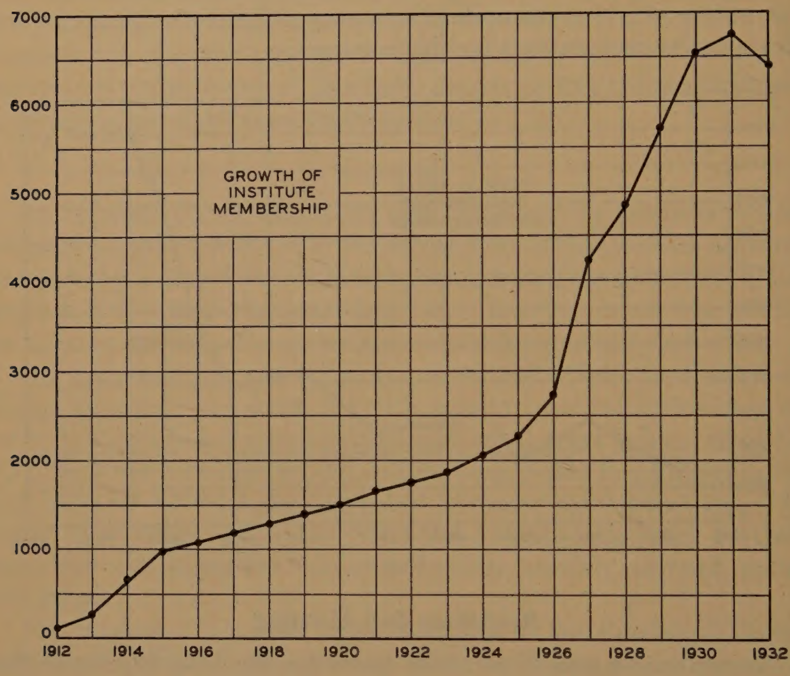


Fig. 2

Admissions

Applications for admission or transfer to the Member or Fellow grades, when received by the secretary, are scrutinized to insure that the number and grade of sponsors and the age of the applicant comply with the constitutional requirements. If satisfactory in these respects, a form is sent to each sponsor to be filled in and returned. When these replies have been obtained and give sufficient data on which to base a decision, the application and all pertinent material is placed in the hands of the Admissions Committee, under the chairmanship of A. F. Van Dyck, for its recommendation to the Board of Directors. There is given below a tabulation showing the classification of the applications considered and the number recommended for approval to the Board of Directors by the Admissions Committee:

	Acted Upon	*Approved*
Transfer to Fellow	2	2
Election to Fellow	0	0
Transfer to Member	29	18
Election to Member	27	16

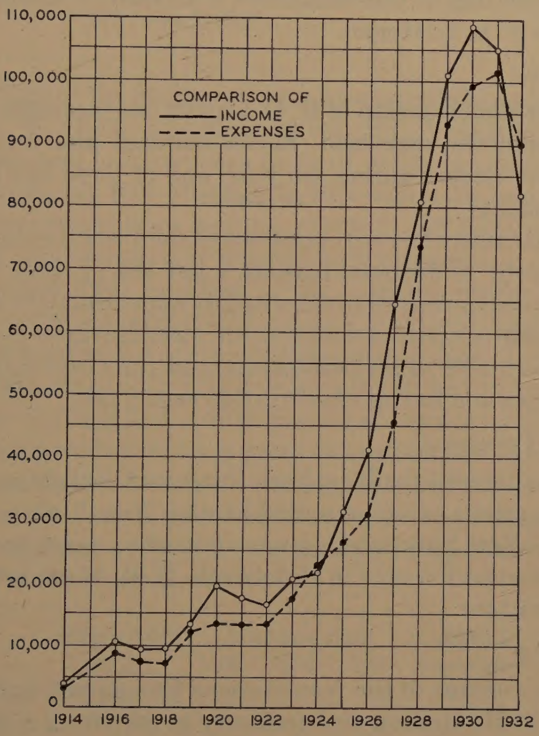


Fig. 3

Awards

Upon recommendation of the Awards Committee, whose chairman is William Wilson, the Institute Medal of Honor was bestowed upon Dr. Arthur E. Kennelly for his studies of radio propagation phenomena and his contributions to the theory and measurement methods in the alternating-current circuit field which now have extensive radio application.

The Morris Liebmann Memorial Prize was awarded to Edmond Bruce for his theoretical investigations and field developments in the domain of directional antennas.

Broadcast

Four meetings were held by the Broadcast Committee, under the chairmanship of E. L. Nelson, which were devoted to an analysis of

broadcasting in the United States as a systems problem. It is anticipated that a report on this subject will be made available during 1933.

Constitution and Laws

As the Institute's Constitution was drastically revised at the end of 1931, no meetings of this committee were held. The chairman of the committee is J. V. L. Hogan.

Membership

Under the chairmanship of H. C. Gawler, six meetings of the Membership Committee were held. Seven hundred and forty-eight new members were elected during the year, and of these one hundred and two were students.

As 1115 members have dropped out of the Institute during the past year, due chiefly to financial reasons, a net loss of three hundred and thirty-one members has resulted which is approximately five per cent. About nineteen per cent of the Institute membership is located outside of the United States or its possessions, and the trend indicates an increasing proportion in this classification each year.

New York Program

Three meetings of the New York Program Committee were held to decide upon papers to be presented at nine New York meetings. The regular April New York meeting was omitted so as not to conflict with the annual convention held in Pittsburgh. E. R. Shute is the chairman of this committee.

Nominations

Only one meeting of the Nonimations Committee under the chairmanship of R. H. Manson was necessary in preparing a slate of candidates for offices for submission to the Board of Directors.

Proceedings

Papers submitted for publication in the Proceedings are reviewed by a member of the Papers Committee and with the report prepared by the reviewer are submitted to a member of the Board of Editors for final decision as to suitability for publication. Some estimate of the quantity of work involved can be obtained from the following tabulation.

Papers reviewed	124
Papers published*	103
Papers rejected	18
Papers returned for revision	19
Book reviews prepared and published	22
Discussions published	8

* Five of these required translation into English.

No meetings of the Papers Committee were held, and only one meeting of the Board of Editors was necessary during the year. The membership of these two groups is not changed greatly each year as their effectiveness depends upon their experience. Dr. Alfred N. Goldsmith is chairman of the Board of Editors and Dr. William Wilson is chairman of the Papers Committee.

Sections

Two meetings of the Sections Committee were held under the chairmanship of C. W. Horn. The first was the annual meeting of the committee and was held in Pittsburgh in April, while the second was held during the Rochester Fall Meeting in November. In both cases, substantial representation from sections resulted, and numerous items of importance in the operation of sections were discussed.

Approximately 2200 members of the Institute reside in the territory alloted to the seventeen sections, and it is estimated that about 1300 additional are within reasonable distance of New York City. Accordingly, 3500 members, or fifty-five per cent of the total membership, have available to them and receive notices of regular meetings.

The following table lists some pertinent information concerning Institute sections. In all cases, conventions, joint meetings, and regional meetings have not been included in the average attendance figures as they do not represent exclusively the interest of Institute members in the activities of the sections.

Section	*Membership as of December 31, 1932*	*Meetings Held*			*Average Attendance 1932*	*Per cent of Average Attendance to Total Membership*
		1930	*1931*	*1932*		
Atlanta	21	4	8	8	18	86
Boston	220	5	5	5	111	50
Buffalo-Niagara	43	7	3	7	55	128
Chicago	260	4	6	8	182	70
Cincinnati	80	8	10	8	45	56
Cleveland	86	8	9	9	57	66
Connecticut Valley	117	1	9	7	37	32
Detroit	101	10	10	10	75	74
Los Angeles	231	10	10	11	68	29
New Orleans	20	2	—	—	—	—
Philadelphia	348	9	8	10	116	33
Pittsburgh	70	9	8	8	37	53
Rochester	51	6	9	4	66	129
San Francisco	182	11	11	10	53	29
Seattle	49	7	10	10	59	120
Toronto	116	7	10	9	75	65
Washington	199	9	9	10	50	25

STANDARDS

The Standards Committee under the chairmanship of J. W. Horton held three meetings to consider reports submitted to it by its six technical committees. These technical committees held twenty meetings during 1932 in finishing their reports which were started in 1931. The report of the Standards Committee with the exception of a few minor items has been approved by the Board of Directors and it is expected to become available for distribution shortly.

Deaths

The following names are those whose Institute membership has been terminated by death:

Austin, L. W.	Johnson, H. F.
Coonley, F. A. W.	Knoll, L. M.
Cowles, E. E.	Nicholas, W. H.
Ferrié G. A.	Sage, F. H.
Hewetson, G. B.	Scholl, R. C.
Sherk, L. E.	

Acknowledgment

Acknowledgment is hereby made of the coöperative and untiring efforts which it has been my good fortune to receive from the headquarters staff during my incumbency as secretary.

Respectfully submitted,

Harold P. Westman

The Institute of Radio Engineers, Inc.

COMPARATIVE BALANCE SHEET

December 31, 1932 and 1931

ASSETS		Dec. 31, 1932	Dec. 31, 1931	INCREASE DECREASE
CASH				
General Fund—Corn Exchange Bank		$ 2,657.40	$ 8,287.37	$5,629.97
Special Fund—Corn Exchange Bank		961.84	1,706.11	744.27
Petty Cash Fund		175.00	175.00	
TOTAL CASH		3,794.24	10,168.48	6,374.24
ACCOUNTS RECEIVABLE—CURRENT				
Junior	$ 22.00		58.00	36.00
Associate	934.29		1,732.77	798.48
Members	14.05		15.00	.95
Entrance Fees	500.00		1,076.50	576.50
Advertising	1,327.77		964.55	363.22
Reprints	45.52	2,843.63	107.82	62.30
ACCOUNTS RECEIVABLE—COLLECTIONS DEFERRED				
Junior	114.00		40.00	74.00
Associate	3,824.66		1,473.00	2,351.66
Member	598.68		255.00	343.68
Fellow	150.00			150.00
Transfer	28.00	4,715.34	60.00	32.00
Due from Chicago Section			579.47	579.47
TOTAL ACCOUNTS RECEIVABLE		7,558.97	6,362.11	1,196.86
INVENTORY				
Proceedings on Hand		4,358.43	4,984.87	626.44
Bound Volumes on Hand		302.00	118.00	184.00
Binders on Hand		138.04	245.14	107.10
Emblems on Hand		327.50	347.20	19.70
TOTAL INVENTORY		5,125.97	5,695.21	569.24
INVESTMENTS—AT COST (Market value 12/31/32/ $29,445.)		55,647.62	57,607.62	1,960.00
FURNITURE AND FIXTURES	8,442.00			
Less—Reserve for Depreciation	4,422.01	4,019.99	4,645.23	625.24
ACCRUED INTEREST ON INVESTMENTS		1,050.76	1,092.43	41.67
PREPAID EXPENSES				
Convention Expense		30.00	238.50	208.50
Unexpired Insurance Premiums		51.38	64.24	12.86
Stationery Inventory—Estimated		400.00	400.00	
Section Expense		41.81	250.00	208.19
TOTAL ASSETS		$77,720.74	86,523.82	8,803.08

LIABILITIES	Dec. 31, 1932	Dec. 31, 1931	INCREASE DECREASE
ACCOUNTS PAYABLE	$ 2,012.68	3,013.97	1,001.29
SUSPENSE	133.95	106.70	27.25
DUES, ETC. PAID IN ADVANCE			
Student	207.00		207.00
Junior		11.50	11.50
Associate	725.53	826.48	100.95
Member	170.48	169.64	.84
Fellow	90.00	7.50	82.50
Entrance Fees	35.00	92.50	57.50
Subscriptions to Proceedings	3,510.80	3,514.65	3.85
Advertising	75.33	64.00	11.33
TOTAL LIABILITIES	6,960.77	7,806.94	846.17
MORRIS LIEBMANN MEMORIAL FUND			
Principal	10,000.00	10,000.00	
Unexpended Income	77.87	77.87	
TOTAL MORRIS LIEBMANN FUND	10,077.87	10,077.87	
DUE EMERGENCY EMPLOYMENT COMMITTEE	647.96		647.96
SURPLUS			
Balance, January 1	68,639.01	64,775.64	3,863.37
Operating Profit or *Loss* for Year	8,604.87	3,863.37	12,468.24
SURPLUS DECEMBER 31	60,034.14	68,639.01	8,604.87
TOTAL LIABILITIES AND SURPLUS	$77,720.74	86,523.82	8,803.08

Patterson and Ridgeway, Certified Public Accountants
74 Trinity Place, New York, N. Y.

Radio Transmissions of Standard Frequencies

The Bureau of Standards transmits standard frequencies from its station WWV, Beltsville, Md., every Tuesday. The transmissions are on 5000 kilocycles per second. Beginning April 1, the schedule will be changed. The transmissions will be given continuously from 12 noon to 2 P.M., and from 10:00 P.M. to midnight, Eastern Standard Time. (From October to March, the schedule was from 10 A.M. to 12 noon, and from 8 to 10 P.M.) The service may be used by transmitting stations in adjusting their transmitters to exact frequency, and by the public in calibrating frequency standards, and transmitting and receiving apparatus. The transmissions can be heard and utilized by stations equipped for continuous-wave reception through the United States, although not with certainty in some places. The accuracy of the frequency is at all times better than one cycle per second (one in five million).

From the 5000 kilocycles any frequency may be checked by the method of harmonics. Information on how to receive and utilize the signals is given in a pamphlet obtainable on request addressed to the Bureau of Standards, Washington, D.C.

The transmissions consist mainly of continuous, unkeyed carrier frequency, giving a continuous whistle in the phones when received with an oscillating receiving set. For the first five minutes the general call (CQ de WWV) and announcement of the frequency are transmitted. The frequency and the call letters of the station (WWV) are given every ten minutes thereafter.

Supplementary experimental transmissions are made at other times. Some of these are made at higher frequencies and some with modulated waves, probably modulated at 10 kilocycles. Information regarding proposed supplementary transmissions is given by radio during the regular transmissions.

The Bureau desires to receive reports on the transmissions, especially because radio transmission phenomena change with the season of the year. The data desired are approximate field intensity, fading characteristics, and the suitability of the transmissions for frequency measurements. It is suggested that in reporting on intensities, the following designations be used where field intensity measurement apparatus is not used: (1) hardly perceptible, unreadable; (2) weak, readable now and then; (3) fairly good, readable with difficulty; (4) good, readable; (5) very good, perfectly readable. A statement as to whether fading is present or not is desired, and if so, its characteristics, such as time between peaks of signal intensity. Statements as to type

of receiving set and type of antenna used are also desired. The Bureau would also appreciate reports on the use of the transmissions for purposes of frequency measurement or control.

All reports and letters regarding the transmissions should be addressed to the Bureau of Standards, Washington, D.C.

Annual Meeting of American Section, International Scientific Radio Union

The American Section of the U.R.S.I. will have its annual public meeting on April 27 at the National Academy of Sciences, 2101 Constitution Avenue, Washington, D. C. This will be a memorial meeting to Dr. L. W. Austin. The Institute is represented on the Executive Committee of this organization, and the PROCEEDINGS is the medium of publication of the papers presented. The meeting is an all-day affair of fifteen-minute papers and discussions. The subjects are in the fields of radio wave transmission, radio measurements, and other scientific questions. Dr. A. E. Kennelly (a former president of the I.R.E.) is the chairman. The exact date, and the list of the papers to be presented, are not available at the time of going to press, but may be secured by anyone interested upon inquiry addressed to the Institute office.

Back Issues of Proceedings

Requests are occasionally received by the Institute office for some of the older issues of the PROCEEDINGS, chiefly those published before 1916. Anyone interested in either disposing of or obtaining such issues, should address the secretary.

Committee Work

BROADCAST COMMITTEE

The Broadcast Committee held a meeting on February 28 in the Institute office, and those present were E. L. Nelson, chairman; Arthur Batcheller, J. B. Coleman (representing B. R. Cummings), J. V. L. Hogan, C. W. Horn, C. M. Jansky, Jr., D. G. Little (representing R. L. Davis), R. H. Marriott, and H. P. Westman, secretary.

The meeting was devoted chiefly to the consideration of a report being prepared on broadcast transmitter performance requirements. The report was not completed, but will be given further consideration at subsequent meetings of the committee.

Constitution and Laws Committee

J. V. L. Hogan, chairman; Austin Bailey, R. A. Heising, E. R. Shute, A. F. Van Dyck, and H. P. Westman, secretary; were present at a meeting of the Constitution and Laws Committee held at the Institute office on February 21.

A number of suggestions presented to the Board of Directors for improving the Institute's Constitution and By-Laws were given preliminary consideration. It is intended that the committee will hold additional meetings and eventually present a report to the Board of Directors.

Convention Papers Committee

The Convention Papers Committee comprising Alfred N. Goldsmith, E. L. Nelson, William Wilson, and H. P. Westman, secretary; met at the Institute office on February 28 to discuss the technical papers program for the Eighth Annual Convention of the Institute. The general problem was given preliminary consideration, and a number of recommendations made which will be given further attention at the next meeting of the committee scheduled to be held late in March.

Membership Committee

At the March 1 meeting of the Membership Committee, which was presided over by H. C. Gawler, chairman, there were present David Grimes, C. R. Rowe, E. W. Schafer, J. E. Smith, and A. M. Trogner.

A letter on membership activities was drafted for subsequent transmittal to the various sections.

New York Program Committee

The New York Program Committee held a meeting on February 14 at the Institute office which was attended by C. W. Horn, chairman; Arthur Batcheller, H. H. Beverage, E. R. Shute, and H. P. Westman, secretary.

The last few New York meetings were reviewed, and programs scheduled for the April and May New York meetings. Some suggestions for future meetings were made.

Standards Committee

A meeting of the Standards Committee held at the Institute office on February 28 was attended by William Wilson, chairman; Alfred N. Goldsmith, H. M. Turner, A. F. Van Dyck, and H. P. Westman, secretary.

The committee discussed generally the Institute's position in the standardization field and outlined a number of policies to guide the

complete committee, the additional personnel of which will be named later. The present abbreviated committee will present a report to the Board of Directors on matters of policy at a later date.

Institute Meetings

Atlanta Section

The annual meeting of the Atlanta Section was held at the Atlanta Athletic Club on January 12, following an informal dinner at which nine were present. Vice-chairman K. P. Tompkins presided in the absence of Mr. Wills.

A vote for officers for the next year resulted in the reëlection of H. L. Wills as chairman and P. C. Bangs as secretary-treasurer. H. L. Reid was elected vice chairman.

A paper on "Engineering Principles Used in the Design of Audio Amplifiers" was presented by I. H. Gerks of the Georgia School of Technology. In his paper, Professor Gerks discussed the characteristics of various types of audio-frequency amplifiers, and showed how the over-all characteristics of amplifiers may be affected through suitable design. The paper was discussed by Messrs. Brewin, Gardberg, and Tompkins.

The second paper on "Interesting Developments in Radio" which was presented by H. L. Reid was discussed by Messrs. Bangs and Dobbs. The attendance totaled fourteen.

Buffalo-Niagara Section

On March 6 a meeting of the Buffalo-Niagara Section was held at the University of Buffalo with L. Grant Hector, chairman, presiding.

A paper on "An Harmonic Analyzer for Audio Frequencies" was presented by G. C. Crom, Jr. of the Colonial Radio Corporation.

In addition to describing the design and characteristics of the harmonic analyzer discussed, the author had a complete set-up of equipment available to demonstrate its operation. A sample class B amplifier was operated, and the relative amplitudes of harmonics were both calculated and measured. The data obtained covered values for the fundamental frequency and harmonics up to the ninth. It was pointed out that an intelligent interpretation of the results of measurements requires a knowledge of acoustics since the amplitude of a harmonic does not bear a direct relationship to the amount of distortion which the ear recognizes it as producing.

The paper was discussed by Dr. Hector who outlined the acoustical aspects of harmonic distortion. The attendance totaled forty-seven.

Cincinnati Section

The annual meeting of the Cincinnati Section was held on December 20 at the University of Cincinnati, and was presided over by C. E. Kilgour, chairman.

In the balloting of officers for 1933, W. E. Osterbrock was elected chairman; C. D. Barbulesco, vice chairman; and Helen Klein, secretary-treasurer.

The paper of the evening, "A Gas Discharge Amplifier," was presented by F. E. Riech and started with a general discussion of the theory of gas discharge tubes and the extent to which they might be controlled. The effects of mechanical relations and the position of the elements and their physical sizes and shapes were considered. Dr. Riech then outlined some early attempts to design and operate such devices, pointing out reasons for their failure. Tubes having emitting cathodes were described and their characteristic curves shown. Some possible applications were considered and additional nonradio possibilities discussed.

Several of the fifty-three members and guests in attendance participated in the discussion.

At the January 17 meeting of the Cincinnati Section held at the University of Cincinnati and presided over by W. C. Osterbrock a report of the Meetings and Papers Committee and a financial report by the secretary-treasurer for 1932 were given. The new officers were installed.

L. M. Perkins of the Erie Resistor Corporation presented a paper on "Composition Resistors and Their Effect on Radio Receiver Characteristics." In it he discussed various types of composition or "carbon" resistors, placing particular emphasis on the various methods used for making contacts with the terminals. An explanation was given of the theory underlying voltage and temperature characteristics of resistors, and the effects of humidity, frequency, and temperature were considered. The cause of variations in resistance resulting in noise was discussed and demonstrated by means of a cathode ray oscillograph which was also used to demonstrate the voltage characteristics of these units.

The paper was discussed by Messrs. Craig, Felix, Kilgour, Osterbrock and others of the fifty members and guests in attendance.

The February meeting of the Cincinnati Section was held on the 14th in the University of Cincinnati. C. W. Osterbrock, chairman, presided and the attendance totaled eighty.

R. M. Wise of the Hygrade Sylvania Corporation presented a paper on "Modern Practice in Radio Tube Manufacture" in which he outlined a brief history of older types of tubes and methods used in their manufacture. The development of higher speed manufacturing equipment with later improvements in tubes was then outlined and followed by a discussion of present processes and equipment used in production at high speeds. Some difficulties encountered were indicated and test methods described. Slides illustrated some of the manufacturing processes and tests employed to insure a satisfactory product.

The paper was discussed by Messrs. Kilgour and Osterbrock.

Cleveland Section

A joint meeting of the Cleveland Sections of the Institute and the American Institute of Electrical Engineers was held on February 16 at the Telephone Building in Cleveland. P. A. Marsal, chairman of the Institute's section, and J. M. Smith, chairman of the Cleveland Section of the American Institute of Electrical Engineers, presided jointly. The attendance totaled 233.

A paper on "Overseas Telephony" was presented by F. A. Cowan of the American Telephone and Telegraph Company.

The speaker traced the growth of overseas telephony service from one circuit connecting metropolitan New York and London which was inaugurated six years ago to the present system through which approximately ninety-two per cent of the world's telephones are available for interconnection. The reasons for the use of long waves on the first North Atlantic circuit and the subsequent employment of short waves both there and elsewhere were outlined.

A special wire connection with the receiving station at Netcong, N. J., was used to demonstrate by loud speaker reproduction in the lecture room the quality of speech received from Daventry, England, as well as the superiority of the horizontal rhombic antenna over one of simpler type. The effect of "privacy" equipment which "scrambles" the speech at the transmitter and "unscrambles" it at the receiver was demonstrated.

The speaker explained that the selectivity and noninterfering features of the horizontal rhombic antenna compare with a simple antenna in the ratio of about one hundred to one. To demonstrate these characteristics, an automobile was stationed near the Netcong receiving antennas. By switching to a simple antenna it was found that noise due to the ignition system of the car was nearly as loud as a signal received from England. With the rhombic antenna no interference of practical importance was heard.

Graphs were projected showing the percentage of time radio circuits to various countries have been available to subscribers and the various frequencies which have proved most dependable at different hours of the day and different seasons of the year. A steady drift toward lower frequencies as being most effective was clearly indicated for the three-year period covered.

Connecticut Valley Section

The Connecticut Valley Section held a meeting on February 23 at the Hotel Charles in Springfield, Mass., with H. W. Holt, chairman, presiding. The attendance was thirty-two.

"Analogies Between Radio and Photographic Techniques" was the subject of a paper by B. V. K. French of the United American Bosch Corporation of Springfield, Mass. The paper had previously been presented at the Rochester fall meeting last November.

A number of analogies between the techniques of radio and photography, of particular interest in view of the fact that photography employs chemical phenomena while radio makes use of electrical and mechanical phenomena, were illustrated by means of slides. Some of the analogies drawn concerned characteristic curves, class A, B, and C operation, amplification, variable-mu tubes, superheterodyne operation, fidelity, and selectivity.

At the conclusion of the paper, the author showed a number of views of an eclipse expedition in which he and several members of the section participated. The discussion which followed brought out a number of odd ideas including that of a light rectifier and a photographic "infradyne." The matter of measuring light in terms of frequency rather than wavelength was discussed. Messrs. Bourne, Hull, Lamb, and Laport entered into the discussion.

Detroit Section

"Transformers and Reactors for Radio Use" was the subject of the paper by R. L. Osborne presented at the February 17 meeting of the Detroit Section in the Detroit News Conference Room.

The author covered the design and construction of transformers and reactors used in modern radio transmitters, receivers, and audio-frequency amplifiers. He outlined various factors encountered in such design, pointing out the relative importance of each and the interdependance of one upon another.

The effect of flux and current densities on the temperature rise, losses, and regulation were discussed, and the importance of selecting insulation capable of withstanding the most severe conditions to be

encountered as well as the effects of temperature and moisture upon its dielectric qualities was considered. Mechanical arrangements of the parts were discussed, and methods used for reducing losses due to magnetic leakage through the clamping system indicated. The paper was concluded with a consideration of features characteristic of transformers designed to operate over a wide range of frequencies, and a brief description of materials used in the general construction of transformers given.

The meeting was presided over by G. W. Carter, chairman. A number of the forty members and guests in attendance participated in the discussion.

New York Meeting

The New York meeting of the Institute was held on March 1 in the Engineering Societies Building. C. W. Horn presided in the absence of Dr. Hull.

Two papers were presented, the first being "Some Notes on Adjacent Channel Interference" by I. J. Kaar of the General Electric Company. In it the author discussed a form of adjacent channel interference which is due either to nonlinearity, misoperation, or misadjustment of the transmitter. The selectivity curve of a modern receiver was shown to illustrate desirable transmitter characteristics. It was pointed out that to eliminate adjacent channel interference, a fidelity of at least sixteen times that which is possible with present-day transmitters would be necessary. Major causes and some of the cures for nonlinearity in transmitters were discussed briefly.

The second paper on "Parasitic Phase and Frequency Modulation" by R. K. Potter of the American Telephone and Telegraph Company and C. R. Burrows of the Bell Telephone Laboratories was presented by Mr. Potter. The differences and similarities of phase and frequency modulation were discussed together with parasitic modulation of this type in relation to the characteristics of short-wave signal paths. The problems of detecting phase and frequency shifts at the signal source were considered. It was pointed out that when modulating the amplitude of a short-wave carrier it is necessary to take certain precautions to prevent the occurrence of parasitic phase or frequency variations. Such effects may seriously distort short-wave signals received beyond the skip range due to the several paths that ordinarily exist between transmitter and receiver. For similar reasons, variations of this kind occurring at the low rate of power supply frequency may greatly accentuate the power hum heard on the carrier at distant reception points. These effects are not readily detected by reception near the transmitter.

A lively discussion followed the presentation of these papers, and was participated in by several of the 200 members and guests in attendance.

Pittsburgh Section

The Pittsburgh Section held a meeting at the Fort Pitt Hotel on February 21 which was presided over by R. T. Griffith, chairman.

"A Description and Discussion of Recent Developments in Radio Tubes" was the subject of a paper by L. E. Swedlund, a research engineer for the Westinghouse Electric and Manufacturing Company.

In this paper, Mr. Swedlund presented a concise and thorough discussion and description of the numerous new types of radio tubes which will be used to a large extent in the commerical broadcast receivers for the ensuing year. With the aid of slides, a very worth-while amount of technical data was conveyed. Following the discussion, participated in by Messrs. Griffith, Mag, Place, Sonnergren, Wallace and others of the thirty-six in attendance, a large number of tubes was displayed.

San Francisco Section

At the February 15 meeting of the San Francisco Section held in the Bellevue Hotel and presided over by A. R. Rice, vice chairman, three papers on the general subject of "Modern Trends in Receiver Design" were presented. The first of these papers on "Developments in Detection and Automatic Volume Control" was presented by H. F. Elliott, a consultant. The second paper on "Some Recent Applications of the New Tubes" was by H. A. Greene, Jr., a radio engineer for the Remler Company, Ltd. F. C. Jones, a consulting engineer, presented a third paper entitled "Image and Noise Suppression Circuits."

Messrs. Heintz, Royden, and Terman participated in the general discussion of these papers, and the attendance totaled seventy of whom twenty-one were present at the informal dinner preceding the meeting.

Seattle Section

At the January 27 meeting of the Seattle Section held at the University of Washington and presided over by H. H. Bouson, chairman, A. R. Willson was appointed chairman of the Meetings and Papers Committee; A. V. Eastman, of the Publicity Committee; and J. R. Tolmie, of the Membership Committee.

The paper presented was on "Radio Beacon Systems," and was by John Greig of the Bell Telephone Laboratories. In his paper, Mr. Greig outlined the progressive development of the conventional crossed-coil beacon citing first its use in the Dole flight to Hawaii and its later

utilization on airways throughout this country. Both the aural and visual reed types were described and compared as to their utility. Limitations were pointed out, and the trend of further development discussed. Another type of beacon was described in which the antenna consists of four vertical radiators spaced as the corners of a square and fed in conjunction with a central vertical radiator in such a manner that the field of radiation assumes a cardioid characteristic which rotates around the station in synchronism with a timing signal from the central antenna. The phase of the two radiations as received on the airplane is compared on a synchroscope calibrated to show the orientation of the beacon station.

Messrs. Bouson, Eastman, Libby, Mason, Mossman, Tolmie, and Willson of the sixty members and guests present, participated in the discussion. Fourteen attended an informal dinner which preceded the meeting.

Toronto Section

The January meeting of the Toronto Section was held at the University of Toronto. R. A. Hackbusch presided and the attendance totaled seventy.

H. W. Parker, chief engineer for the Rogers Radio Tubes, Ltd., who was assisted by F. J. Fox of the Rogers Majestic Corporation of Canada presented a paper on "Spray Shield Tubes."

The author showed that the spray shield not only acts as an electrostatic shield but has other definite electrical effects. He reviewed early work of spray shielding and described the present-day methods of manufacture. Illustrations were shown of special machines developed to apply the shielding as an automatic process. It was pointed out that it is absolutely essential for the shielding material to be embedded in the glass, and its effect in equalizing the temperature over the envelope treated.

A joint meeting of the Toronto Sections of the Institute and of the American Institute of Electrical Engineers was held at the University of Toronto on February 10. The meeting was presided over by I. M. MacLean, chairman of the Toronto Section of the A.I.E.E.

"Television" was the subject of the paper by J. O. Perrine of the American Telephone and Telegraph Company. In it Dr. Perrine explained the principles of each of the main components used in television transmission and reception, giving practical demonstrations of photocells, glow lamps, scanning disks, and similar equipment. A description of each of these units was presented and their applications outlined.

They were then demonstrated as a combined unit. The various circuits employed were shown by means of slides.

The attendance at the meeting totaled 575.

Washington Section

H. G. Dorsey, chairman, presided at the February 9 meeting of the Washington Section held at the Kennedy-Warren Apartment Hotel.

"The Madrid Communications Conference" was the subject of the paper by J. H. Dellinger, chief of the Radio Section of the Bureau of Standards.

Dr. Dellinger pointed out that the radio and telegraph conference held in Madrid resulted in a new unification of international message services and the adoption of a new word "telecommunication." This word will be used to include telegraph, telephone, cable, and radio communication. All are regulated under the new International Telecommunication Convention signed by all nations. Detailed provisions to become the basis of laws in the various countries are given in so-called Regulations accompanying the Convention, one set of Regulations covering telegraphy, another covering telephony, and two provided for radio.

The speaker explained the origin of the convention and the relation of the Madrid conference to previous conferences. He pointed out that this was the first time that wire and radio services were dealt with in a single convention. While the United States delegation is a signatory to the convention and the radio regulations, it is not a party to the telegraph or telephone regulations.

An effort was made at Madrid to provide for expansion of broadcast services by assigning more frequencies. This was opposed by representatives of marine and aviation interests from whom some of the frequencies would be taken. The conclusions reached were that if such changes are to be made, they should be made in each region independently. These controversies are to be continued in regional conferences to be held this spring, one in Europe and one in North America.

Dr. Dorsey read a letter from the Washington Academy of Sciences announcing the affiliation of the local section with the Academy, and the Executive Committee appointed Dr. Dellinger representative of the Washington Section.

The attendance at the meeting totaled forty, and fifteen were present at the preceding dinner.

Personal Mention

Colonel A. G. Lee formerly vice president of the Institute has been named Engineer in Chief of the British Post Office.

J. C. McNary formerly a consulting engineer has been named assistant to the managing director of the National Association of Broadcasters.

Previously with the General Electric Company, W. A. Fitch has joined the radio engineering staff of the National Broadcasting Company in New York City.

Formerly with the Northern Wireless Relay Company, A. Cross has become supervising engineer of the Standard Radio Relay Services of London, England.

T. F. Johnston formerly in the Baltimore office of the Federal Radio Commission is now an engineer in the Geophysics Division of the Texas Company of Houston, Texas.

W. H. Grosselfinger previously with American Airways, is now radio engineer in charge of radio and electrical systems for Ludington Air Lines at Washington, D. C.

V. J. Andrew formerly of the University of Chicago, has joined the X-ray development department of the Westinghouse Lamp Company at Bloomfield, N. J.

F. E. Golder has recently been advanced to vice president in charge of radio engineering and traffic of the Southwest Broadcasting Company.

Previously with the Phillips South African Electric Corporation, G. N. P. Allaway, has established a consulting practice in Durban, South Africa.

Alfred Crossley formerly chief engineer of Howard Radio has established a consulting practice with the firm Arnold, Dunn and Crossley in Chicago, Ill.

Previously with the Dutton Radio Institute, G. H. Dutton has become chief engineer of Gold Seal Television and Supply Corporation of Newark, N. J.

Lieutenant L. M. Harvey, U.S.N., has been transferred from the U.S.S. Louisville to the U.S.S. Neches.

Lieutenant C. M. Johnson, U.S.N., has been transferred from the U.S.S. Bushnell to the U.S.S. Holland.

Previously with the Tropical Radio Telegraph Company, R. C. Jones has become radio engineer for the Kansas City Fire Department in Kansas City, Mo.

J. H. Muller has been transferred from the Hawaiian Islands to the Manila, P. I., branch of RCA Communications.

Formerly with the RCA Victor Company, I. S. Pierson has become affiliated with the Stackpool Carbon Company of St. Mary's, Pa.

Previously with the Peter Smith Stamping Company, I. B. Serge has joined the radio engineering staff of Colonial Radio Corporation of Buffalo, N. Y.

T. R. Smith a radio engineer for All America Cables has been transferred from Nicaragua to Bogota, Colombia.

C. F. Stromeyer formerly with the Cable Radio Tube Corporation is now chief engineer for Revelation Patents Holding Company of New York City.

J. P. Thornton of RCA Communications has been transferred from Rocky Point, N. Y., to Kohuku, T. H.

Proceedings of the Institute of Radio Engineers
Volume 21, Number 4 *April, 1933*

TECHNICAL PAPERS

CONTINUOUS KENELLY-HEAVISIDE LAYER RECORDS OF A SOLAR ECLIPSE*

By

H. R. Mimno and P. H. Wang

(Cruft Laboratory, Harvard University, Cambridge, Mass.)

Summary—*A new type of apparatus, which makes a continuous automatic record of the varying heights of the Kennelly-Heaviside layers over a long period of time, has been designed. The history and the preliminary experiments are mentioned briefly. Two models are described and illustrated. The first model is a fixed piece of radio-transmission laboratory equipment, designed for maximum flexibility in operation. The second model is a light, compact, portable recorder, designed for field use.*

An expedition was sent to New Hampshire during the total solar eclipse of August 31, 1932. Continuous records of layer heights were made during the entire week of the eclipse. The portion of the record obtained on the afternoon of August 31 shows definite, abnormal variations of large magnitude. The F layer record shows two high peaks, with a minimum at totality, accompanied by double refraction effects. The first peak occurs forty minutes before totality, and the second peak occurs forty minutes after totality. The observations agree with the measurements made by another field expedition, and with additional records made by the laboratory apparatus in Cambridge, Mass.

I. Introduction

THE eclipse measurements reported in this paper have been made during the early stages of an extensive research project, recently undertaken by Harvard University. The following paragraphs will describe the apparatus developed for the general program, as well as the special devices employed on the eclipse expedition. The Harvard expedition coöperated with another group of observers led by G. W. Kenrick and G. W. Pickard. Their experimental results are reported in the following paper. The two independent measurements were made at different receiving points, but the experimental results are in good general agreement, and the two sets of observations supplement each other.

The continuous recorder of Kennelly-Heaviside layer heights is a relatively new experimental tool, independently developed by several different laboratories in order to trace the very complex and rapid changes in the transmission path. The existence of such changes has been indicated by numerous oscillographic experiments, based on the pulse transmission method.

* Decimal classification: R113.61×R113.55. Original manuscript received by the Institute, December 19, 1932. Presented before Boston section, October 14, 1932.

[1] G. Breit and M. A. Tuve, "A test of the existence of the conducting layer," *Phys. Rev.*, vol. 28, pp. 554–575; September, (1926).

The pulse method was originally used with an ordinary mechanical oscillograph.[1] The galvanometer oscillograph produces a permanent record of the effective layer height at a given instant, but it uses several meters of sensitized film or paper per second, and is obviously unsuitable for continuous use. The film speed cannot be reduced without loss of resolving power. Consequently this form of oscillograph has been used only for intermittent "snapshot" observations. Measurements of this sort were very useful in demonstrating the *existence* of "multiple reflections" "round-the-world signals," etc. The information obtained from intermittent readings is necessarily incomplete, however, since important changes sometimes occur in a fraction of a second. Furthermore, the resolving power of the instrument is limited by the mechanical inertia of the oscillograph mirror, which becomes objectionable when we attempt to measure time intervals smaller than 0.0005 second. The oscillograph element requires a comparatively large amount of current for successful operation. This is not a serious difficulty in a fixed installation, since we can operate a number of tubes in parallel in the amplifier output stage, or use a special low impedance tube, but it is inconvenient in a field expedition with a limited power supply. Step-down transformers have sometimes been used in such cases, but the resulting audio-frequency transient introduces new complications in operation and interpretation.

Some improvement results from the use of a cathode ray oscillograph.[2,3] The observers can watch the continuous changes in the reflection pattern, and record their measurements in a notebook. This method is useful if we limit the duration of the experiment to a few hours. In the case of the eclipse measurements reported in this paper, the experiment was carried on almost continuously for one week. Several years will be required for an adequate study of the correlation of Kennelly-Heaviside layer heights with sun spot variations, magnetic storms, auroral displays, partial eclipses, and the like. In an experiment of this nature the human observer must be replaced by a machine. The reflection pattern changes continually, and does not repeat its cycle accurately from day to day or from year to year. It must also be noted that some of the most interesting changes occur so rapidly that the human eye cannot follow them on the oscillograph screen. The cathode ray tube is very useful as a monitor device, but we no longer use it for recorded observations.

[2] G. Goubau and J. Zenneck, "Messung von Echos bei der Ausbreitung elektromagnetischer Wellen in der Atmosphäre," *Jahr. der drahtlosen, Tel. u. Tel.*, vol. 37, pp. 208–218; June, (1931).

[3] J. P. Schafer and W. M. Goodall, "Kennelly-Heaviside layer studies employing a rapid method of virtual-height determination," Proc. I.R.E., vol. 20, pp. 1131–1148; July, (1932).

Obviously, the ideal apparatus should make an automatic record, and the record should be compact and easily readable. The apparatus should be rugged enough to operate without frequent interruptions for service or adjustment. With such a device it would be possible to establish a permanent and complete file of Kennelly-Heaviside height records, covering a period of several years. These records would be available for comparison with height measurements observed by other recording stations, and for comparison with all other geo-magnetic and geo-electric data. The resolving power of the instrument should be higher than that of the mechanical oscillograph. The power output required from the receiving set should be small, and the input impedance of the recorder should be high. These requirements have governed the development of the recorders described in the following pages.

II. Historical Outline

In its most simple form the continuous recorder resembles the apparatus used in telephotograph reception. Most of us have noted the "ghost" images formed on a television screen, as a result of multiple path transmission. Similar effects occur in high speed radio telephotograph experiments. The received picture sometimes consists of two images which are slightly displaced, the amount of displacement depending upon the time lag of the sky wave behind the ground wave. If several sky waves are present, the number of displaced "ghost" images is correspondingly increased. The resulting distorted picture therefore contains a continuous record of the transmission conditions encountered during the time required to transmit the photograph. Obviously, we may simplify the photographic record by transmitting the photograph of a very simple object, such as a single straight horizontal line. Experiments of this nature were reported very briefly by H. Rukop[4] in 1926. The ground wave produced a single straight line on the film at the receiving point. The reflected waves contributed additional lines, approximately parallel to the first, but showing certain irregularities due to changes in time lag and intensity. The experiments were apparently performed with standard commercial apparatus, and represented an engineering study of the difficulties encountered in telephotograph transmission rather than an extensive physical survey of atmospheric ionization. Consequently the resolving power of the apparatus was rather low, and the duration of the record was very short.

A recorder of somewhat different pattern was proposed in a pre-

[4] H. Rukop, "Die Bildtelegraphie als Untersuchungsmethode fur die Ausbreitung der kurzen Wellen," *Elec. Nach. Tech.*, vol. 3, pp. 316–318; August, (1926).

liminary paper by Gilliland and Kenrick[5] in 1931. They used the galvanometer oscillograph as the basis of their design, and intended to produce a permanent photographic record of the image formed by the usual synchronous mirror. They therefore substituted a slit, and a slowly moving film, in the place of the ordinary ground-glass screen. The authors point out certain difficulties that might arise in the interpretation of records, as a result of the fact that each pulse may illuminate the slit twice. We now know that this would have been a serious limitation if they had attempted to record the very complex patterns which apparently result from the splitting of transmission paths in a doubly refracting medium. This type of recorder has been superseded but it represents an interesting transition from the mechanical oscillograph method.

In commencing our own research program, several preliminary experiments were undertaken.[6] A number of sample "snapshot" observations were first made by means of a "long-film" galvanometer oscillograph. The instrument is similar in general pattern to the devices used by many previous investigators,[7] but the speed of the paper tape is somewhat higher than usual. (This is made possible by the use of a magnetic clutch, magnetic brake, and a special type of shock absorber, which accelerates the tape from rest to a uniform speed of 10 feet per second, in approximately 0.001 second. The deceleration is equally effective, and it is possible to spread out the time scale without wasting large amounts of paper.) The first-hand information obtained with this device proved useful in surveying the general field to be covered in designing the new recorders. The cathode ray oscillograph experiments described by Zenneck and Goubau[2] were repeated in order to secure additional information in regard to receiving set transients, and in regard to the rapidity of changes in effective layer height. While this general information was being obtained, it was also necessary to make a group of experimental tests in order to select a suitable optical system for the recorder.

III. Preliminary Tests of Recording Lamps

Having decided that the record should be made by a modulated beam of light, moving over sensitized photographic paper, we ex-

[5] T. R. Gilliland and G. W. Kenrick, "Preliminary note on an automatic recorder giving a continuous height record of the Kennelly-Heaviside layer," *Bureau of Standards Journal of Research*, vol. 7, pp. 783–789; November, (1931); Proc. I.R.E., vol. 20, pp. 540–547; March, (1932).

[6] H. R. Mimno and P. H. Wang, "New devices for recording Kennelly-Heaviside layer reflections," (Abstract), *Phys. Rev.*, vol. 41, p. 395; August 1, (1932); (Abstract), *Wireless Engineer*, vol. 9, p. 632; November, (1932).

[7] W. A. Marrison, "Oscillographs for recording transient phenomena," *Bell Sys. Tech. Jour.*, vol. 8, pp. 368–390; April, (1929).

amined several different types of "light valves" and light sources. The galvanometer oscillograph type of light control was rejected on account of mechanical inertia and low impedance. The Kerr cell, frequently used in telephotography, was seriously considered, and might have been successfully used. The gaseous discharge lamp was finally adopted, however, as it is exceedingly simple and reliable, and requires very little operating power. It is, therefore, well adapted for use in an instrument which must operate for long periods without attention. The light is modulated at its source and the optical efficiency is high. Several different types of "crater lamps" and "glow lamps" have recently been developed for commercial use in television and telephotograph devices. After trying a number of lamps and lens systems we finally selected a "recording lamp" which is now manufactured for use in motion picture "sound cameras." A similar lamp was described by F.Schröter[8] in 1928. Neon gas is usually used, with a slight amount of nitrogen or argon to improve the photographic effect. The discharge takes place between adjacent coaxial cylinders and the resulting light can be focused in a small, sharply-defined spot on the photographic paper. At a "film speed" of 400 centimeters per second it is possible to record the individual light and dark patches produced by a 10,000-cycle alternating current, superposed on the direct current which excites the discharge. With the aid of a low power microscope we can readily distinguish individual lines, when their centers are spaced one fortieth of a centimeter apart. A modulating voltage of 3 volts (root-mean-square) will produce a visible record when connected in series with the 350-volt battery supply. Somewhat larger signal voltages are desirable in order to secure greater contrast in the record, but it is apparent that a simple power detector, or one-stage resistance-coupled audio amplifier, may supply an adequate recording voltage. This glow lamp draws only 0.5 milliampere in normal use and appears to have a long life under such conditions. It is a high impedance device and is therefore well suited to vacuum tube operation.

The advantages predicted by the preliminary tests were later tested during many hours of operating practice, with entirely favorable results. The gaseous discharge lamp is well suited to automatic recording, and has been adopted by other laboratories. It was independently selected by Rukop and Wolf[9] for use in recorder experiments reported in 1932.

[8] F. Schröter, "Fortschritte in der Bildtelegraphie," *Elec. Nach. Tech.*, vol. 5, pp. 449–458; November, (1928).

[9] H. Rukop and P. Wolf, "Eine leistungsfahrige Einrichtung fur Messungen an der Heavisideschichten," *Zeits. für tech. Phys.*, vol. 13, pp. 132–134. March, (1932).

IV. Drum Type Recorder

A general view of the drum type of recorder is given in Fig. 1. An aluminum cylinder, 17.8 centimeters in diameter and 95 centimeters in length is mounted in an engine lathe and rotated by a 60-cycle synchronous motor. The recording lamp is mounted on the tool carrier of

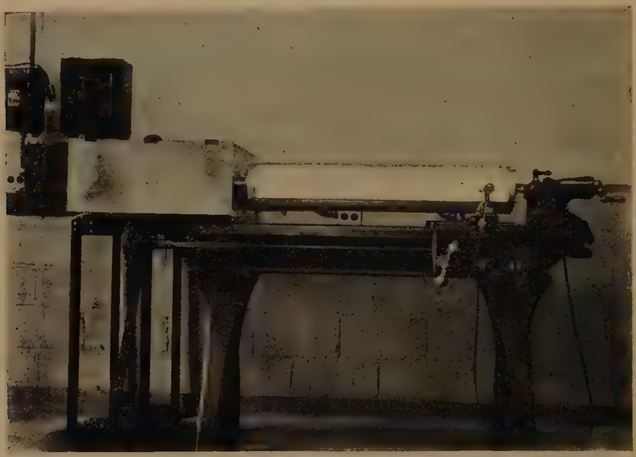


Fig. 1—Rotating drum type of recorder.

the lathe, being enclosed in a horizontal brass tube which also supports the lens. The optical system is indicated in Fig. 2. An intense spot of light, about one quarter of a millimeter in diameter, is focused on a sheet of photographic paper which is clamped on the periphery of the

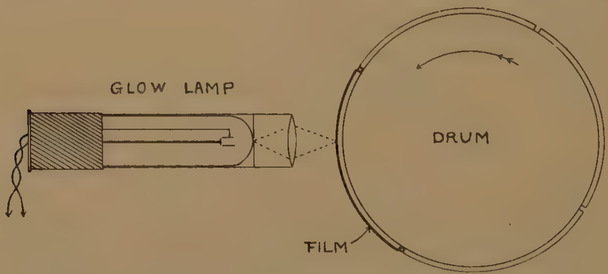


Fig. 2—Optical system. Rotating drum recorder.

rotating cylinder. The tool carrier is drawn slowly along the lathe bed by the lead screw. The unmodulated spot of light would therefore trace a helix on the cylinder, drawing successive evenly spaced lines on the paper. The pitch of the helix is determined by the engine-lathe change gears. We have greatly supplemented the usual range of change

gears by the use of double compounding, and by the introduction of worm gears. Without changing the peripheral speed we can therefore change the traverse speed through wide limits.

Fig. 3 presents a more detailed view of the mechanism, with the gear box open, In order to maintain a synchronous speed, we have removed the usual cone pulleys, replacing them by chain sprockets. Different synchronous peripheral speeds can be obtained, however, by changing the position of the drive chain on the sprockets, and by use of the lathe back gears. In practice we ordinarily use a peripheral speed of approximately 400 centimeters per second. It will be noted that the apparatus may be described as a high speed chronograph with a variable time scale.

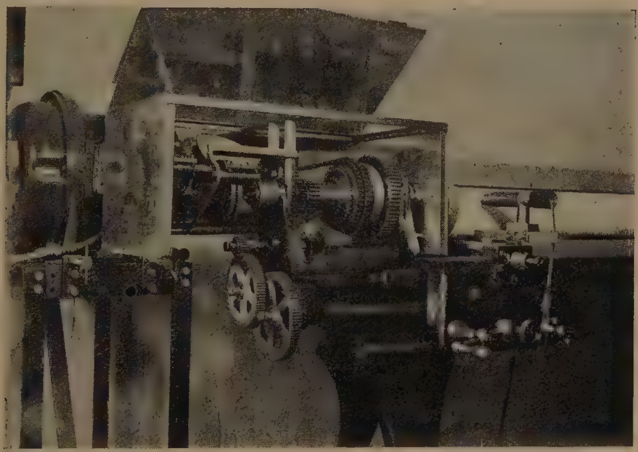


Fig. 3—Gear box. Rotating drum recorder.

The transmitting set sends out a series of evenly spaced pulses, of short duration. The spacing is determined by a commutator, or equivalent device, synchronized on the 60-cycle power network which also drives the recorder drum. The ground wave arrives first at the receiving station, and the resulting pulse in the receiving set causes a momentary increase in the intensity of the traveling spot of light. This prints a black dot on the moving paper, which is quickly followed by additional marks as the successive "reflected" waves arrive and are recorded. As the drum rotates in synchronism with the transmitter pulses, additional ground wave dots are printed adjacent to the first, forming a straight line, parallel to the axis of the cylinder. The various sky waves form irregular broken lines which alter in position, intensity, and width as the transmitting conditions change.

V. Typical Continuous Records

Fig. 4 presents two sample records taken by this original drum type of recorder on successive days in June, 1932. The transmitting set was located about two miles away, at Tufts College, and operated on a frequency of 3492.5 kilocycles. The pulses were produced by a simple commutator, which closed a grid circuit in the transmitting amplifier. The duration of the pulse was approximately 0.001 second. The horizontal black line, on the upper record, represents the ground wave pulses received during the night of June 11–12. The irregular

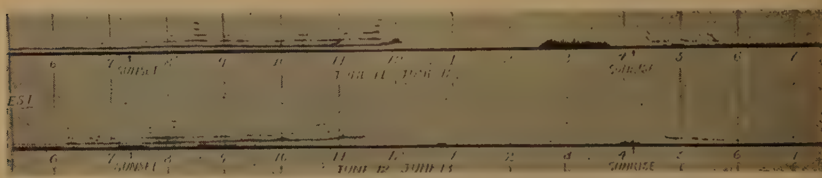


Fig. 4—Behavior of ionized layers on two successive summer nights.

broken lines above it represent the various sky waves. Reflections from a low layer are represented by lines which are almost in contact with the ground-wave base-line. For convenience in interpreting the time scale we have drawn light vertical lines on the record at one hour intervals. The record begins shortly before 6 P.M., June 11. At this time there are intermittent reflections from a high layer (approximately 300 kilometers). About 7 P.M. the reflection becomes stronger, and weak second-order and third-order reflections appear occasionally. The third-order reflection is sometimes stronger than the second. (This probably indicates a favorable polarization of the downcoming third-order wave.) At 8:20 the number of multiple reflections suddenly increases to six, and this high reflecting power is maintained about ten minutes. About 11 P.M. the first-order reflection splits into two parts. (Such effects are usually ascribed to magneto-ionic double-refraction.) The weaker part rises very rapidly, and fades out. The main F layer rises slowly, as numerous multiple reflections again appear for a short time. About midnight the F layer disappears with a final upward surge, accompanied by broad "thunder roll" echo.

During this entire period the E layer has not been observed at all. About 2:30 A.M. it suddenly appears. Four multiple reflections can be distinguished on the original record, but they appear as a single black area on the small-scale reproduction. These reflections last about an hour and a quarter, vanishing at 3:45, about 25 minutes before sunrise.

Sunrise occurs about 4:10. Ten minutes later the F layer reappears

at approximately 600 kilometers, and falls to 300 kilometers in a few minutes. It then vanishes, and the process is repeated several times during the next few hours, but the layer does not persist. Meanwhile a weak E layer has also reappeared at frequent intervals, and it finally remains.

The lower half of Fig. 4 represents the record obtained during the next night. The behavior is similar in general, but the F layer lifts earlier, and an E layer may be noted occasionally in the early evening. It also appears briefly at 1 A.M. and again at sunrise. After sunrise the E layer is missing, and the F layer is somewhat less turbulent than on the previous day. The double refraction effect is not observed on this record.

It will be necessary to take a large number of these records before we can derive any general conclusions. We know that the F layer sometimes persists through the entire night at this frequency. Fig. 4 has been introduced merely to illustrate the type of information which we may expect the continuous recorder to furnish.

VI. The Portable Recorder

Having tested the general principle of the new recorder, and determined all the necessary operating margins experimentally, we were able to design a lightweight compact outfit for field use. This is not intended to replace the original laboratory model, but to supplement

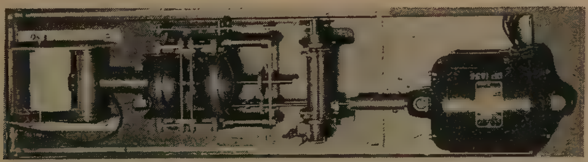


Fig. 5—Top view of portable recorder. Photographic tape has been removed in order to show the interior mechanism.

it. A general view of the newer apparatus is given in Fig. 5. The same recording lamp and electric circuit are employed, but it will be noted that the mechanical system has been altered. The lamp remains stationary, projecting a beam of light along the axis of rotation of a mirror, which is rotated at high speed by a countershaft geared to a small synchronous motor. (Fig. 6.) This mirror deflects the beam through an angle of 90 degrees, and it is then brought to a sharp focus by a lens which rotates with the mirror. The resulting spot of light sweeps across a strip of photographic paper tape, which is given a slow longitudinal motion in a direction parallel to the axes of the motor, lamp, and ro-

tating mirror. The sensitized tape is 8.5 centimeters in width. It is guided by two pairs of curved polished wooden rollers which bend the paper to form a section of a cylinder as it passes the rotating spot

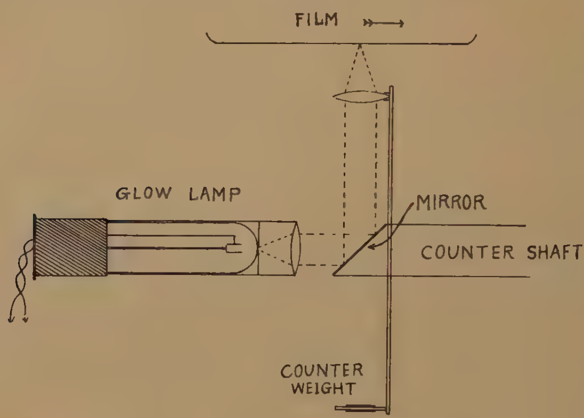


Fig. 6—Optical system. Portable recorder.

of light. This cylinder is 12.8 centimeters in diameter and its axis coincides with the axis of lamp and rotating mirror. The traveling spot of light, therefore, remains in exact focus as it crosses the tape. By using

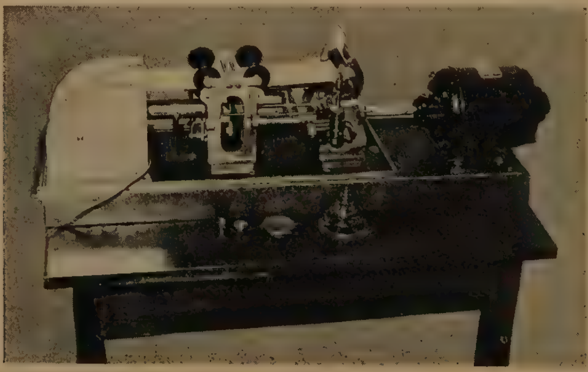


Fig. 7—Side view of portable recorder. Photographic tape in place.

such a sharply defined pencil of light it is possible to obtain high resolving power with a comparatively short optical path. The recorder resolving power may be altered at will by changing the gear ratio between motor and mirror. In the eclipse experiments this resolving power was apparently limited only by the receiving set transients. It will be noted that the high-speed mechanical parts of the optical system consist merely of the mirror and lens. The lens is approximately 4 centimeters

from the axis of rotation, and is counterbalanced in order to avoid vibration.

Fig. 7 shows a side view of the apparatus. The slow longitudinal motion of the sensitized tape is produced by the same synchronous motor which rotates the mirror and lens. The gear train also operates a mechanical shutter, which interrupts the beam of light every fifteen minutes, in order to mark a time scale on the record automatically when desired. The tape speed may be altered through wide limits by means of change gears in the reduction train. A relatively high speed was used during the eclipse period in order to record possible rapid changes. The length of the record is limited only by the capacity of the reels which carry the paper. The paper is punched, and is driven by a sprocket, in order to secure a positive uniform speed, independent of the reel diameter. The entire assembly is protected by a light-tight cover (not shown in the photographs), and may be operated in daylight when necessary.

VII. The Eclipse Expedition

With this apparatus a number of records were made during the period of the recent solar eclipse. The eclipse occurred August 31, 1932. Records were obtained on this day and also on the two preceding days and on the four following days. The more important records were made by a field expedition at points within the track of the total optical eclipse. The choice of such a location is somewhat arbitrary, since the optical eclipse occurs further south at the higher atmospheric levels where refraction must take place. On the other hand it is evident that a possible corpuscular eclipse may be most effective at points further north. On the whole, the ground totality region seems to represent a good compromise, since it is definitely located, and offers a reasonable chance for the direct comparison of our results with measurements on future eclipses.

The Harvard section of the eclipse party was led by Mr. Wang, (as the senior member of the group was several thousand miles from the scene on the date of the eclipse). He was assisted by several members of the Cruft Laboratory staff, who were making optical observations in the same section of New England. By courtesy of the Navy Department, a suitable transmitter location was provided at the Portsmouth Navy Yard for the joint use of the Tufts College expedition and the Harvard expedition. The two groups did not use the same receiver location, however. Our receiving apparatus was located at Durham, N. H., about 15 kilometers west of Portsmouth, in a room provided by the University of New Hampshire. The recorder was placed in a dark room in the basement of the same building.

A photograph of the transmitting equipment is presented in Fig. 8. Synchronization of transmitter and receiver was accomplished by operating on the same 60-cycle power net. In order to decrease the duration of the transmitted pulse, a grid-blocking circuit, somewhat similar to that described by Appleton,[10] was employed. However, the usual grid-blocking circuit produces pulses with a spacing which depends on the time constants of the grid circuit, and it is therefore necessary to introduce a control voltage for synchronizing on a power network.

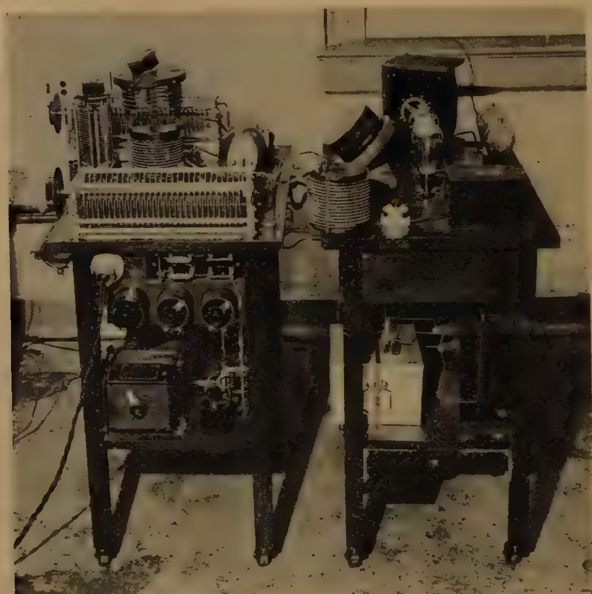


Fig. 8—Transmitting equipment used at Portsmouth.

This can be done by modulating the grid or plate voltage at 60 cycles. We find it convenient to adjust the grid leak until natural blocking occurs approximately 30 times per second, when the alternating voltage is not connected. The application of a control voltage then pulls the pulses into exact synchronism and prevents drift. Under this condition there seems to be no appreciable fluctuation in phase, although the pulse location does occasionally jump by a whole cycle. For normal film speeds, the paper recording tape is wide enough to prevent loss of the record in such a case. A shift of half a cycle may be produced at will by merely reversing the alternating voltage leads. Cathode ray

[10] E. V. Appleton and G. Builder, "Wireless Echoes of short delay," *Proc. Phys. Soc.*, vol. 44, pp. 76–87; January 1, (1932).

oscillograph measurements on the oscillator plate current indicate that the pulse duration is not greater than 0.0001 second. The actual width of the ground-wave base-line recorded on the photographic tape was determined by the audio-frequency time constant of the receiving set. This was a standard commercial receiver, consisting of a short-wave converter and a superheterodyne broadcast set. By measuring the displacement of the lower edge of the sky-wave line from the corresponding edge of the ground-wave line, it was possible to determine the layer heights with an uncertainty of approximately 10 kilometers. The photographic record may be further improved by a more careful design of the receiving set, but the available apparatus was adequate for the study of the large variations which occurred during the eclipse period.

VIII. Eclipse Records

The layer height measurements taken during abnormal conditions, provided by a solar eclipse, must be compared with similar records taken under normal conditions. As yet we have not accumulated enough records to predict the normal behavior at an arbitrary frequency and a given season of the year. The recorder is a new instrument, and we have spent more time in improving the machine than in taking systematic daily records. For this reason we made a special effort to determine a background for comparison purposes on the days immediately preceding and following the eclipse. These control records were made under exactly the same conditions as the eclipse record. The work of the Harvard section was concentrated on the frequency 3492.5 kilocycles. The records taken on the control days do not differ in essential details, and it is possible to draw a curve representing the normal average layer height as a function of the time of day. This curve is plotted as a dotted line in Fig. 10. At 1 P.M. the apparent F layer height is approximately 215 kilometers. It rises slowly during the afternoon, reaching a maximum of 315 kilometers about 4:30 P.M., and then falls gradually.

Fig. 9 is a photograph of the part of the record obtained during the eclipse period (reduced in scale about 5:1). For convenience in reproduction, the tape has been divided in eight sections. Each section represents 30 minutes. The top section begins at 2:00 P.M., Eastern Standard Time. The bottom section ends at 6 P.M. The remainder of the original record shows no effects which we can ascribe to the eclipse. At Durham the partial eclipse began at 2:19 P.M. The total optical eclipse lasted from 3:29:47 to 3:31:16. The partial eclipse ended at 4:33. The Portsmouth figures are practically the same. The disturbance at 2:05 has no significance, as it represents interference from another trans-

mitting station. On account of the high tape speed used during the eclipse period, the changes in layer height may appear to be somewhat slow. They are indicated more clearly by the solid curve, plotted in Fig. 10. At 2:30 the F layer rises abruptly from its normal value, attaining a high maximum shortly before 3:00 P.M. The total rise is more

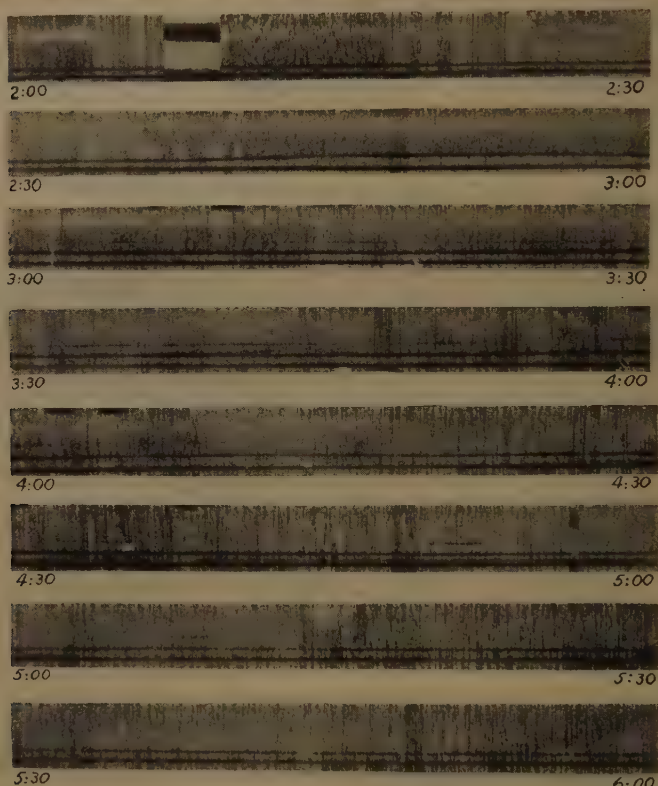


Fig. 9—Photograph of the eclipse record obtained at Durham.

than 100 kilometers. It then drops to a broad minimum near the time corresponding to total optical eclipse. At this time the height is slightly over the normal value, indicated by the dotted control curve. After totality the F layer again rises abnormally, and attains a second maximum at 4:10. It rejoins the normal curve about 4:30, and then shows minor irregularities which may be due to the approaching sunset period.

Other reflections appear on the same photographic record. There is a weak broken line which appears to represent a mere second-order intermittent reflection from the main F layer. This interpretation is checked by the fact that the extra line fades out when the main F layer rises as a result of decreased ionization. We have not indicated this reflection in Fig. 10 since it gives no new information. A more interesting line appears about 3:20. This line is too faint for good reproduction in Fig. 9, but it is clearly visible on the original tape. The line has been plotted in Fig. 10. It represents a splitting of the F layer,

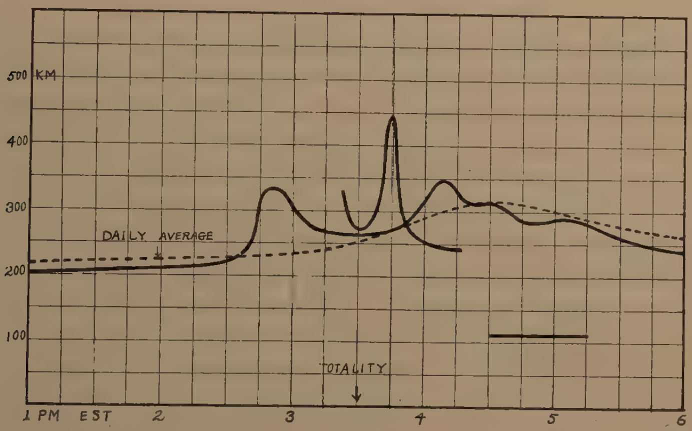


Fig. 10—Layer heights during the eclipse period.

similar to that noted in Fig. 4. The effective height of this weak "reflection" is of the same order of magnitude as that of the F layer. The height goes through a sharp minimum at totality, followed by a very sharp maximum fifteen minutes later. It then drops below the height of the main F layer and fades out. About 4:30 we begin to notice a fairly strong reflection from the E layer, which lasts about 45 minutes with some changes of intensity, but with little fluctuation in height. This is not an unusual occurrence at this frequency, and it is not necessarily a consequence of the eclipse.

These observations are in good agreement with similar records made by Kenrick and Pickard on the day of the eclipse, and described in the following paper.

In addition to the field observations, the Portsmouth transmission was recorded on our original fixed apparatus at the Cruft Laboratory in Cambridge. This was made possible by courtesy of the New England Power Company, since it was necessary to hold the Portsmouth power

network in synchronism with the Boston network for a longer period than is customary. In this case the path of transmission extended from a point in the totality belt to a point in the partial eclipse zone 80 kilometers farther south. No ground wave was received at this point, however, and the Cambridge record merely gives supplementary information. At this distance one must expect some phase fluctuations in the power net.

Fortunately a low layer reflection was present on this path during a portion of the eclipse period preceding totality, and we may use the time lag between E and F reflections as a rough measure of the large changes in the height of the F layer. When examined in this manner, the Cambridge record *also* indicates a sudden rise in the F layer with a maximum shortly before 3 P.M. The useful portion of the Cambridge record is therefore in satisfactory agreement with the Durham record.

IX. Discussion of Results

We do not wish to draw any theoretical interpretation from the observations until a much larger amount of data has been obtained under normal conditions, and during other eclipses. At present we are primarily interested in obtaining additional experimental information. An important result of the present experiment is the clear indication that an eclipse effect does exist. The changes in layer height are large and rapid. It is known that a severe magnetic storm took place a few days before the eclipse, but the random variations which were observed on the control days do not approach the eclipse variations in magnitude or duration. A sufficient number of similar measurements may enable us to analyse the various possible causes of atmospheric ionization. It is probable that partial and annular eclipses will produce measurable effects. It will be especially desirable to make measurements on an eclipse which occurs earlier in the day. In any event, the character of the observed changes appears to justify the expenditure of a considerable amount of time and effort on future measurements of the same type.

Preliminary reports from other groups of American and European physicists indicate that the older methods of observation were unable to detect significant changes in layer height before the approximate time of optical total eclipse, and this has led to the impression that the corpuscular eclipse (if present at all) did not produce any measurable effect. Under these circumstances the double peak obtained by our continuous recorder is of especial interest. The first peak occurred about forty minutes before totality. This strongly suggests a corpuscular effect on the high layer, although we are not yet willing to rule out

other possibilities. The corresponding records obtained by Kenrick and Pickard at a different geographical location are in excellent agreement with our own curves, and show a similar double peak.

X. Conclusions

It appears certain that a solar eclipse may produce ionization changes of large magnitude. It is probable that further study of these changes will be of service in testing the causes of atmospheric ionization. The continuous recorder is a satisfactory instrument for the systematic study of the Kennelly-Heaviside layers.

In conclusion we wish to thank the following persons and groups for their coöperation during the experiment: Dr. Pickard and Dr. Kenrick, the Navy Department, the University of New Hampshire, and the New England Power Company. We are also indebted to a number of our friends at Cruft Laboratory for advice and assistance in the construction of the recording apparatus and its installation at Durham.

Proceedings of the Institute of Radio Engineers
Volume 21, Number 4 *April, 1933*

OBSERVATIONS OF THE EFFECTIVE HEIGHT OF THE KENNELLY-HEAVISIDE LAYER AND FIELD INTENSITY DURING THE SOLAR ECLIPSE OF AUGUST 31, 1932*

By

G. W. Kenrick

(Electrical Engineering Department, Tufts College, Massachusetts)

and

G. W. Pickard

(Consulting Engineer, Newton Center, Massachusetts)

Summary—*The result of observations of the effective height of the Kennelly-Heaviside Layer on frequencies of 1640, 3492.5, and 4550 kilocycles are described. On the higher frequencies two height maxima, one before and one after totality, are observed. These maxima occur at approximately 50 per cent totality.*

Field intensity observations on 6095, 940, and 16.1 kilocycles taken at Tufts College are also described, and a marked eclipse effect is found on the two higher frequencies. The nature of the field intensity variations observed is in good agreement with those anticipated as a result of observations during the eclipse of 1925.

I. Introduction

The purpose of this paper is to describe the results of observations made during the solar eclipse of August 31, 1932. These observations were of the effective height of the Kennelly-Heaviside layer on frequencies of 1640, 3492, and 4550 kilocycles, and field intensity on 16.1, 940, and 6095 kilocycles. It is of interest to note that this is the first use of continuous Kennelly-Heaviside layer recording during a solar eclipse.

Much of the data secured is in the form of photographic or pen-recorder records. Space does not permit the reproduction of the originals of all the records secured, and when the interpretation is clarified and space economized, comparative curves derived from a study of all available data are utilized. Fortunately, equipment smilar to a considerable portion of that used has been described in previous publications, and, where such descriptions are available, references are made only by bibliography. However, inasmuch as the understanding and interpretation of the records shown in many cases depend upon a clear understanding of the conditions under which they were taken, it has seemed advisable to include a brief description and photographs

* Decimal classification: R113.61×R113.5. Original manuscript received by the Institute, October 25, 1932. Presented before Boston Section, October 14, 1932.

of set-ups employed in cases where such details are not available in print. This was the situation with respect to the layer height recording equipment which, while in no sense unique in principle, involved numerous modifications in mechanical detail from that previously employed.[1,2,3]

II. Kennelly-Heaviside Layer Height Determinations

(a) Transmission Paths

The observations of the virtual height of the Kennelly-Heaviside layer utilized the pulser method of Breit and Tuve extended to give continuous statistical records of layer height conditions which were secured by the use of automatic recording equipment similar to that previously described.[2,3] These observations utilized two transmitters of 250 and 500 watts capacity operated, respectively, on frequencies of 3492.5 and 4550 kilocycles located at the Portsmouth, N. H., Navy Yard, and a 100-watt transmitter at the Short Wave and Television Laboratories at Boston, Mass., operating on 1640 kilocycles. The receiving location for the pulse transmissions was Seabrook Beach, N. H. These observations included all three frequencies, i.e., 1640, 3492, and 4550.

(b) Transmitters

The transmitting and antenna facilities at Portsmouth are shown in Figs. 1a and 1b, which show the antenna orientation, the building used to house the equipment, and the orientation of the equipment. Both of these transmitters were operated as self-oscillators, and were caused to emit very sharp pulses (about 2×10^{-4} seconds) by the use of a high time constant grid-leak grid-condenser circuit which caused the oscillations to cease, due to blocking, within this duration of their start. The 30-pulse-per-second group frequency employed was secured by the aid of a 60-cycle alternating voltage in the grid circuit, which was found fairly satisfactory for locking in the pulses synchronously with the alternating-current supply. The 30-cycle group frequency was secured by an appropriate choice of the 60-cycle voltage and the grid-condenser grid-leak time constant so that the degree of recovery from the blocking action was sufficiently slow to permit the oscillations to start only on the second positive cycle after the occurrence of the oscillation blocking section sequence responsible for the

[1] Gilliland and Kenrick, *Bureau of Standards Journal of Research*, vol. 7, no. 5, November, (1931); *See also* Proc. I.R.E., vol. 20, no. 3, pp. 540–549; March, (1932).

[2] Mimno and Wang, *Bull. Amer. Phys.*, vol. 7, no. 4, p. 20, (1932); Proc. I.R.E., this issue, pp. 5-9–545.

[3] Rukop and Wolf, *Zeit. Tech. Physik*, vol. 13, pp. 132–134, (1932).

emission of the pulses. The circuit described was found reasonably stable and no great difficulty was experienced in adjusting the circuits to the emission of a series of pulses, which did not differ in phase by more than one degree (i.e., about 10^{-4} seconds) on successive alternating-current cycles. A fairly constant group frequency of 30 per second was also readily maintained, but considerable trouble was experienced on some occasions due to a tendency of the pulses to "pick up" or "drop" one cycle (i.e., 1/60 second) resulting in a change in the "frame" of the received trace, which was in many cases an important consideration. A more detailed discussion of the results of this effect will be introduced in the section on "Receiving Set-ups." (See also reference (2).)

Fig. 1a—Transmitter location and antenna structures at Portsmouth Navy Yard (Kittery, Maine).

By appropriate choice of the poling of the alternating-current grid bias transformers for the two sets, it was, of course, possible to cause the grids of the two oscillators to swing positive on alternate halves of the alternating-current cycle, and to insure thereby a time diversity in the occurrence of the pulses, which was utilized at Seabrook Beach to permit the recording of two frequencies on the same recorder, thereby enhancing the amount of data obtainable with the amount of equipment available. The change of frame is avoidable provided the time constants of the transmitters are slightly readjusted so that a pulse is emitted each 1/60 second. Such an expedient, however, reduces by one half the maximum delay, which it is possible to measure without ambiguity, due to the arrival of another ground pulse before the echo.

On the Seabrook Beach equipment high resolution was used and the shifts encountered were hence extremely troublesome, since they not infrequently resulted in the complete loss of the record for a considerable period. These difficulties will be discussed in greater detail later in this paper.

The circuit employed in these transmitters is essentially that described by Appleton, and was first developed for use with the 3492.5-kilocycle transmitter which was supplied by Harvard University, and also observed at Durham, N. H.[2] The antennas used at Ports-

Fig. 1b—Inside view of building housing transmitters. 500-watt (modified) Navy transmitter is shown on right; 250-watt transmitter on left.

mouth are shown in Fig. 1a. On 4550 kilocycles, the T antenna with an approximately 60-foot lead-in and a flat top of 150 feet was used, while on the 3492 kilocycles the sloping wire to the left-hand pole shown was employed. The length of this wire was approximately 150 feet. Both antennas were energized to ground. The 4550-kilocycle transmitter and the facilities at the Portsmouth Navy Yard were supplied with the kind coöperation of the Naval Research Laboratory and the Bureau of Engineering.

The transmitter utilized for the 1640-kilocycle transmissions was the one usually utilized by the Short Wave and Television Labora-

tories for the transmission of television signals. A mechanical chopper driven by a synchronous motor was utilized to key the transmitter, which was of a conventional MOPA type.

The 1640-kilocycle transmitter employed a T antenna with 130-foot flat top and 75-foot vertical down lead. In layer observations it is desirable to record carefully the type of antenna structures employed, both at the transmitter and receiver, since numerous investigators[4] have emphasized the importance of these structures in determining the characters of the observed results. The limited time available for apparatus preparation, however, required the antenna systems utilized to be governed more by convenience and expediency than as a result of careful design or tests.

The T structure was originally erected for use as a multiple-tuned doublet and when so operated probably gave a much higher proportion of high-angle radiation. Due to the considerable ground wave distances employed, however, substantial low-angle radiation was essential, and it is believed the systems employed were not an undesirable compromise as the ratio of sky-to-ground wave at the receiving points was still found to favor the sky waves, particularly under night conditions, and the ground wave amplitudes were none too large for reliable operation.

Superior operation could, it is believed, have been obtained had it been found feasible to operate over a short ground wave distance and utilize higher angle radiators, but the choice of the location for the temporary set-ups was governed also by expediency, and the availability of facilities on the whole were found to be quite satisfactory. The major disadvantages of the long ground wave path were found in adjustment at the receivers during periods of high noise level such as were usually encountered in the early evening, due to summer static, etc. This period, of course, occurred simultaneously with the most rapid phase changes over the long connecting systems, and made visual checks on the forming of the recording pattern difficult. These phase changes were also a difficulty aggravated by the long ground wave distance as well as by the character of the intervening tie lines.

A further discussion of these points is to be found in another section.

(c) *Receiving Equipment at Seabrook Beach, N. H.*

The quantitative Layer Height observations conducted at Seabrook Beach, N. H., were all secured with automatic recorders of the Neon lamp type, energized from radio receivers and appropriate amplifiers of

[4] deMars, Gilliland, and Kenrick, "Kennelly-Heaviside layer studies," Proc. I.R.E., vol. 19, no. 1, pp. 106–113; January, (1931).

conventional design. In the case of the 1640-kilocycle observations, a Baird television receiver was utilized directly to energize the Neon lamp in one of the two available recorders, while in the case of the higher frequency observations the output of two "all-wave" receivers (tuned to 3492 and 4550 kilocycles) were condenser-coupled to the lamp of the second recorder, which was hence doubly energized. Time diversity in the occurrence of the pulses, however, avoided confusion of the records due to the two frequencies. (See II (b) for description of pulsing method employed.)

The appearance of the main recorder assemly utilized at Seabrook Beach is shown in Fig. 2.

Fig. 2—Assembly of recor.'er for 3492.5- and 4550-kilocycle channels showing receivers, rotating lamp, and cameras.

The mechanical details of the particular equipment utilized at Seabrook Beach were evolved mainly with a view to simplicity and availability of equipment, so that the set-up could be constructed and placed in operation in the very limited time available for the work. Little attention to mechanical details and refinement was hence possible.

As no light-tight box is provided for the equipment it is necessary to operate it in a photographically dark room to prevent fogging the films associated with the recorders. This difficulty could, of course, be overcome by housing the equipment in a light-tight box of suitable size. Such an arrangement was contemplated, but abandoned for lack of time. As the size of the apparatus is considerable, however, it is believed preferable to preserve the present practice of operating the equipment in a dark room, but the associated receivers should be removed to another point in the interest of availability and general con-

venience. The light shielding of the receivers was, in fact, a troublesome detail, and resulted in high temperatures therein due to the abnormal amount of heat insulation introduced with the light shielding.

The essential characteristics of the recorder are shown in Fig. 2. As shown, the device consists essentially of a tube containing at one end a point-source gaseous lamp, which is supplied with voltage with the aid of the top set of brushes and binding posts shown in Fig. 2. The other end of the tube, which is telescoped and adjustable in length to permit focusing, contains a spectacle lens of approximately one foot focal length. The image of the point of light from the gaseous lamp can thus be photographed or observed on a film or screen placed in line with, and approximately one foot from, the end of the tube. Preliminary adjustments in focus may be made by telescoping the tube or moving the screen or film; the latter method is usually convenient for final adjustments. The lamp is supplied with voltage from the output of the receivers as in the case of a conventional television receiver, and since time diversity in the transmission of the pulses was employed, it was possible to excite the grid of the final output tube in the stage connected to the lamp from the output of the two receivers, thereby superposing the inputs, which did not interfere because of the time interval between the two sets of pulses.

If, now, the lamp assembly is rotated with the aid of a synchronous motor and reduction gear assembly such as shown in Fig. 2, and if the lamp is excited from the output of a receiver tuned to a transmitter which is being keyed by a chopper driven by a synchronous motor supplied from the same or a synchronized source of power, the succeeding pulses produced in successive rotations and recorded on the screen or photographic film will stand still (that is, be superposed along the θ-axis). If sky waves are present, other pulses will, of course, follow the direct or ground wave transmission pulse (see Fig. 4). If, now, the recording film is given a slow motion along the axis of Z, a straight line (due to the ground wave pulse) and a series of curves produced by sky waves will be produced on the film (along this axis). The form of the record thus obtained is shown in Fig. 6. A schematic view looking down on the recorder is perhaps of assistance in clarifying the set-up. Since the lamp assembly is geared down to turn only a few revolutions per second, the pattern will be found to repeat at frequent intervals around the circle described by the focus of the spot and a large number of records may be taken simultaneously if desired by introducing cameras at various points, as indicated in the schematic diagram of Fig. 4. Thus, in the design shown the lamp is rotated synchronously at two revolutions per second, and, since the synchronous choppers

employed give 30 pulses per second, there are 15 equally spaced points around the circumference at which the ground wave appears. The camera may be introduced at the point which proves the most convenient. The speed of rotation and optical arm distance from the center of rotation chosen is dictated by the degree of resolution desired, mechanical expediency, and the desirability of keeping the linear velocity across the film constant (that is, observed angle small). All these considerations indicate a fairly slow velocity of rotation. Very slow veloci-

Fig. 3—Modified recorder assembly with stationary lamp.

ties, however, give pulses on the screen so seldom that visual monitoring of the occasional flashes becomes more difficult and exposure time for the film is unjustifiably reduced. The brush and slip ring connection of the neon lamp to its external circuits was found to be a prolific source of disturbance in the associated receivers, presumably because of the small current in this circuit. In the recording equipment used for the 1640-kilocycle transmission, a modification in the original design was hence effected in which the neon lamp and lens were held sta-

tionary, the light beam being rotated by a totally reflecting prism driven by a synchronous motor. This form of assembly, which is shown in Fig. 3, is believed to be preferable to the rotating lamp type, and is being used in further observations utilizing the equipment described here. These observations will be presented in a later paper.

The cameras constructed for use with the assembly (shown in Fig. 2) consist of drums rotated by telechron chart movement mechanisms designed to produce one revolution (i.e. about 12 inches of film) every six hours. The drum is, however, housed in a light-tight box containing two compartments, one of which contains a roll reservoir of film, which is wound up on the moving drum in multiple layers as it turns. This permits more than one revolution of the drum (six-hour interval) with one loading. Greater time resolution is provided for by a second chart

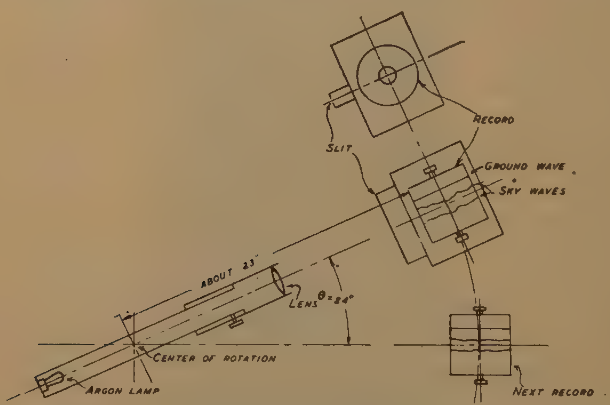


Fig. 4—Schematic view showing principle of operation of recorder.

movement running at six times the speed which may be alternately engaged at the other end of the shaft when higher speed records are desired.

The compartment housing the moving drum is provided with a slit shielded with a visor to reduce stray light, and permits the point image from the lamp to be focused on the film. The appropriate position of the box along the circle described by the focus of the light beam is determined by first finding the pulse image (produced when the lamp is energized while rotating) on a ground-glass plate and then introducing the camera carrying the film in the proper position with respect to the r and θ axes (see Fig. 4).

The position along the r-axis is, of course, adjusted to bring the spot in sharp focus on the film, and the position in θ is chosen to bring the ground wave trace near the edge of the film first traversed by the

moving spot. In this connection, it should be noted that the appropriate position in θ will, in general, change each time the synchronous motor at either the transmitter or receiver is stopped. It is hence desirable to keep these motors as nearly as possible in continuous operation, modifying the transmitter's operation when necessary by keys in series with and parallel with the chopper. It is possible to reframe by rotating the position of the motor at the receiving point along its axis of rotation or by rotating the motor or brushes at the transmitter where a chopper is employed. Various positions are also secured by successively starting the motor at either point and noting the positions in which the system pulls in. The number of positions possible is more

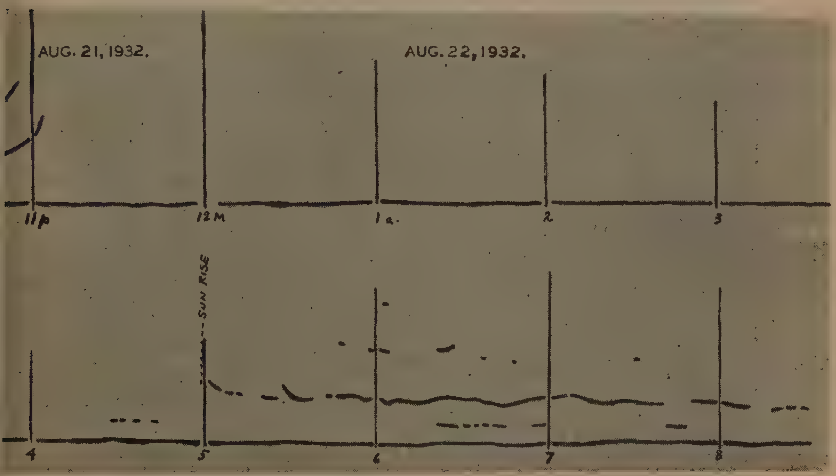


Fig. 5—Record of layer height during early morning hours of August 22. 1932, Note rise and disappearance of F layer at 11 P.M., and appearance of E layer and fall of F layer during dawn period.

than might be expected at first thought, and the desired position may frequently be obtained by successive trials (say eight or ten). As a last resort the position of the camera may be altered. However, since the focus is rather critical, this is not particularly desirable, it being preferable to fix this position by wooden guides for the base of the camera to insure that it is replaced in proper alignment after it has been removed for reloading. This was done during the tests, and the position of the origin line was adjusted by restarting the motor at the receiver.

Timing of the photographic traces is secured by short-circuiting the lamp at hourly intervals through mercury pool contact and extensions attached to the minute and hour hands of a telechron clock. (Shown in Fig. 2.) The slower motion of the hour hand provided a longer break in the record every 12 hours. (See Fig. 5.)

The type of records obtained by this equipment is shown in Fig. 5. In addition to illustrating the traces obtained and the timing, these records are of some interest in showing the rather abrupt rise and disappearance of the F layer which seems typical of night conditions on the frequencies observed. The phenomena of falling layer normally accompanying dawn are also admirably illustrated in Fig. 5. Another

Fig. 6—Photographic record as observed at Seabrook Beach, New Hampshire, showing layer height variations on 3492.5 and 4550 kilocycles during eclipse.

surprising phenomenon shown (and one which appears in many records) is the appearance of marked reflections from the E layer at an interval of several hours preceding dawn, and the normal fall of the F region. These phenomena are now being made the subject of more extended investigations.

The writers wish to express to the Rumford Fund Committee their grateful appreciation for the grant from the Rumford Fund adminis-

tered by the American Academy of Arts and Sciences, which provided for the recording apparatus used at Seabrook Beach and described above.

(d) Comparison of Virtual Height Observations During Eclipse

Fig. 6 shows the actual photographic record obtained at Seabrook Beach, N. H., for frequencies 3492.5 and 4550 kilocycles during the eclipse period. The lower trace shows the 3492.5 traces while the upper trace (single except for a weak reflection near totality) shows the 4550-kilocycle phenomena. The layer height variation during totality (and during the late afternoon) as derived from this and similar records is plotted in Fig. 7.

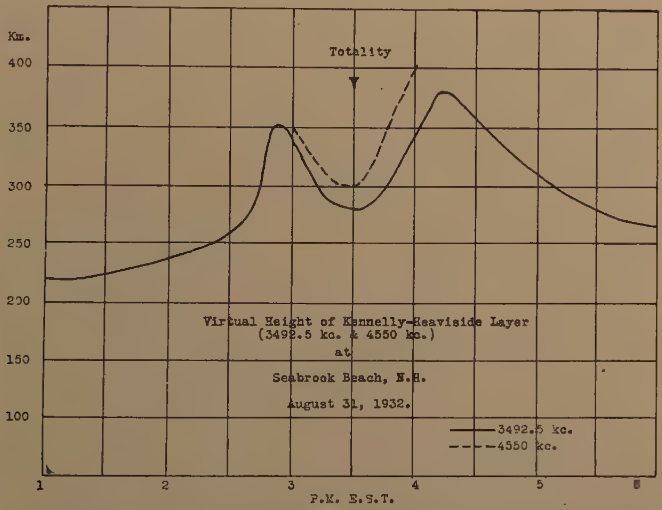


Fig. 7—Comparison of virtual height on 3492.5 and 4550 kilocycles during eclipse of August 31, 1932, Kittery, Maine, transmission to Seabrook Beach, N. H.

The ground wave lines (lower lines) shown in Fig. 6 are practically straight except for breaks due to phase changes. The upper traces for each frequency vary in time delay (and hence in separation from the lower trace) according to the virtual height of the layer. The distance of separation between their traces is linearly proportional to the effective height of the layer, except where traces due to multiple reflections enter in harmonic relation, as will be noted at totality, in the case of the 3492.5-kilocycle trace. Here the higher traces represent multiple reflections rather than high layers.

In the scale on the original record 200 kilometers layer height equals one centimeter on the record. It will be noted that the virtual height rises from 230 kilometers at 2:30 P.M. to a maximum of 380 kilometers

at 3 P.M. E.S.T., and then falls to a minimum of 280 kilometers (still well above the day level) at totality. Another rise to 400 kilometers occurs following totality, followed by a subsidence to a normal value (260 kilometers) at 6 P.M. (as shown in Fig. 7). The large virtual heights before and after totality and rather moderate rise from normality at the time of totality are perhaps at first thought very surprising until it is recalled that the heights recorded are virtual rather than true heights. Discussion of these results in the light of all the available height and transmission data and the available knowledge of the mechanism of the layer changes as derived from previous observations

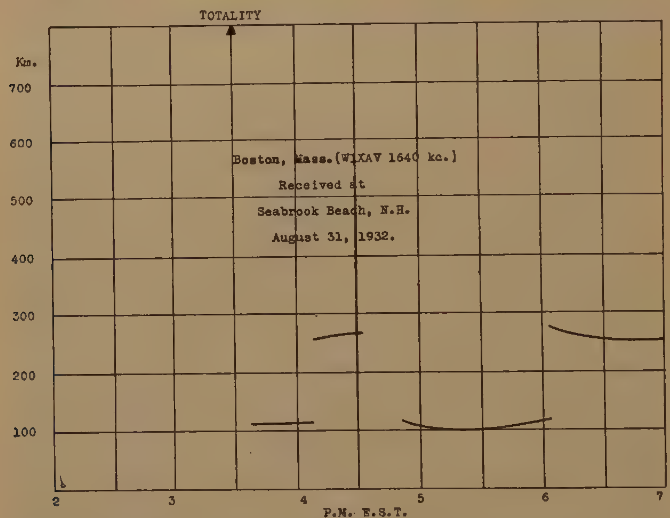


Fig. 8—Virtual height on 1640 kilocycles during afternoon of August 31, 1932, Boston, Mass., to Seabrook Beach, N. H., transmission path.

and theory will be found in another section of this paper. Before proceeding to this discussion, it is, however, desirable to examine the phenomena as observed on all the frequencies. It will be noted that the results on 4550 kilocycles (also recorded in Fig. 6) also show a virtual height minimum and maximum of intensity at totality. The intensity of the reflection is faint on this frequency and is only recordable for a brief period. Of course, no abrupt changes during the middle afternoon period were observed in the effective height of the layer on the days preceding and following the eclipse, and the changes recorded on these frequencies on August 31 are so distinctive as to be without doubt true eclipse effects.

Fig. 7 shows a comparative plot of the values of virtual height obtained during the eclipse for 3492.5 kilocycles and on 4550 kilocycles.

The results for the Seabrook Beach-Boston transmission on 1640 kilocycles are shown in Fig. 8. The resolution both in time scale and in height was in the case of the 1640-kilocycle record such that a possible error of several minutes exists in the transition times shown, and the height scale is hardly considered to be determinable to better than 20 kilometers due to low resolution of the recorder used in this record. However, this record is of particular interest in that it approaches closest to the broadcast frequency range where some of the field in-

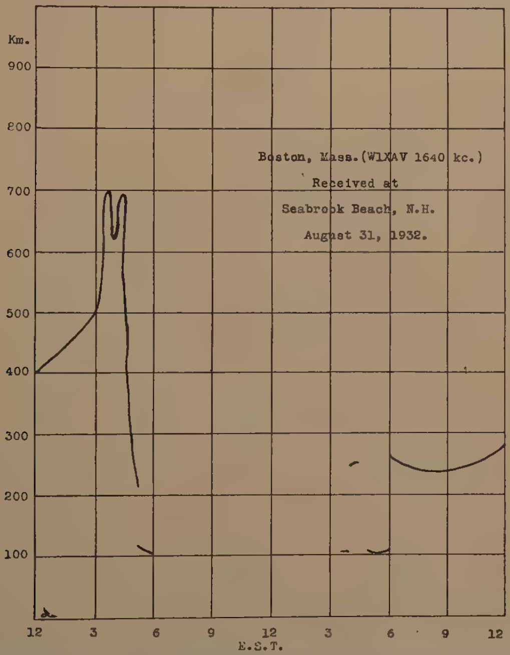


Fig. 9—Virtual height on 1640 kilocycles during twenty-four hours of August 31, 1932, on 1640 kilocycles, Boston, Mass., to Seabrook Beach, N. H. transmission path.

tensity records were taken, and is the only height record which shows evidence of a lag effect similar to that described in the next section in connection with the broadcast field intensity observations. In this case it is, of course, possible that the changes observed were not uniquely due to the eclipse, but represented a composite due to several causes. However, observations on the previous and following days showed no recordable sky waves at times as early at 4 P.M., and the appearance of the F-layer reflections at this time (a marked sunset effect) is not considered probable in the absence of eclipse effects. Thus it will be noted that this frequency shows the appearance of an E layer, fol-

lowed by a transition to the F region followed by a disappearance of reflections. The record for the twenty-four hours of August 31, 1932, on 1640 kilocycles is shown in Fig. 9.

III. Field Intensity Observations During the Eclipse

(a) *VE9GW (6095 Kilocycles)*

The field intensity variations for VE9GW (Bowmanville, Ont., Canada) as received at Tufts College, Medford, Mass., during the afternoon of the solar eclipse (August 31, 1932) are shown in Fig. 10. While transmission on this frequency over this path is normally sub-

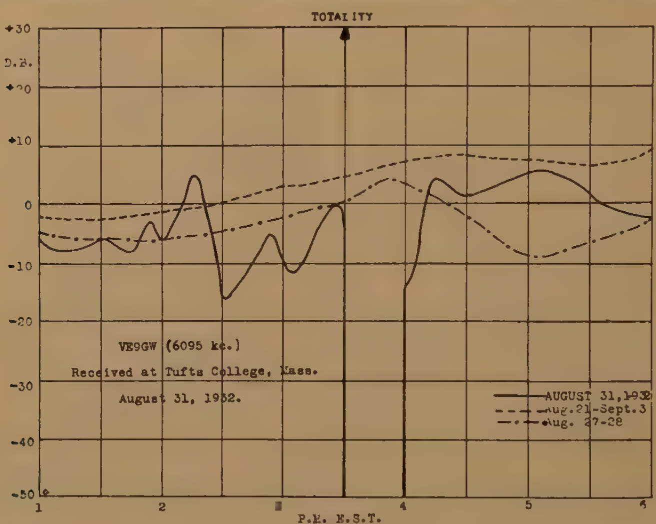


Fig. 10—Field intensity variation of VE9GW during eclipse of August 31, 1932. (Transmission path from Bowmanville, Ont., Canada, to Medford, Mass.)

ject to marked fading, a mean curve for the period from August 21 to September 3 indicates that an abrupt drop in field intensity, such as that shown during the eclipse, is distinctly abnormal during the mid-afternoon period, although such phenomena may occur during the sunset period and are a normal occurrence during the late evening.

While it is, of course, impossible to deduce entirely conclusive evidence from the single record available during this eclipse, it seems very probable that the marked reduction of field coincident with totality is a true eclipse effect. It will be noted that the field intensity fell rather abruptly to a value below the range of the recorder about two minutes before totality at Tufts College, and remained below a recordable value until 4 P.M., when it again rose rapidly. This type of variation (characteristic of the night effect for this frequency) is substan-

ially identical with that recorded on a four-megacycle channel during he eclipse of 1925.[5] The apparatus employed in making these observaions was that constructed under a previous grant from the Permanent cience Fund and regularly employed at Tufts College for measurenents in this frequency range.[6]

Due to the limited schedules which broadcast stations in this frequency region usually follow, it is not in general possible to obtain a eries of diurnal curves of signal intensity extending over the entire wenty-four-hour interval. During the period preceding and following he eclipse, however, VE9GW agreed to remain in continuous operaion for a number of days. This permitted a study of the diurnal hanges associated with this transmission path. A curve for one such wenty-four-hour run is shown in Fig. 11. It will be noted that this urve shows a marked reduction in field intensity at about 8 P.M. E.S.T. apparently associated with a sunset effect. A marked cut-off is lso to be noted at 10:30 P.M. The 8 P.M. fade is not typical and is apparently a somewhat abnormal sunset effect, but the sharp cut-off at 0:30 P.M. is so abrupt as to suggest a signing-off of the station. A heck against the log of the station, however, showed that it was mainained in operation during the entire twenty-four-hour period. A rise n field at about 12:30 A.M. from the 10:30 P.M. fall is also rather ypical and appears in enough records to appear in the average curves or the available runs, which are also shown in Fig. 11. for periods where sufficient points are available to make the means significant. uch means, however, tend to give a somewhat fallacious idea of the xtent of the fading in individual records because of the smoothing hey introduce. The curve for a particular twenty-four hours is, thereore, perhaps more illustrative of the conditions ordinarily observed.

b) *WCSH (Portland, Maine) (940 Kilocycles)*

Observations from WCSH in Portland, Maine, operating on a frequency of 940 kilocycles were also carried out at Tufts College for everal days including August 31, 1932. The apparatus employed for hese observations was that usually devoted to recording the field inensity of WBBM in Chicago, and has been described in a previous ublication.[6] Due to the logarithmic response of this equipment and he substantial ground wave, the variations appearing on the original ecord are to a much less than linear scale so that a plot of sky wave

[5] G. W. Pickard, Proc. I.R.E., vol. 13, no. 5, p. 567, Fig. 23; October, 1925).

[6] deMars, Kenrick, and Pickard, "Use of automatic recording equipment in adio transmission research," Proc. I.R.E., vol. 19, no. 9, pp. 1613–1633; eptember, (1931).

(i.e. departures from the ground wave mean due to fading) is most suggestive. Plots showing these variations for the day of the eclipse and the day following are shown in Fig. 12.

With the kind permission of P. A. de Mars, technical director of the Shepard Broadcasting Service, the writers are also able to show a curve of field intensity changes for WCSH as taken at Epping, N. H., during the afternoon of the eclipse. The close accord of the time of the

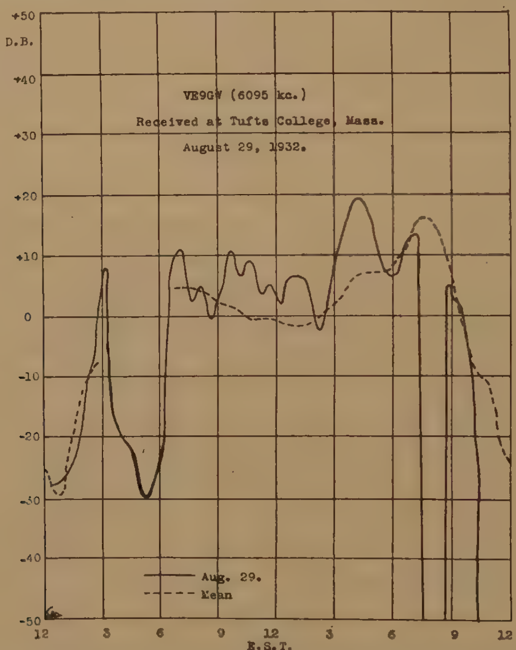


Fig. 11—Field intensity variation of VE9GW for twenty-four hours of August 29, 1932. (Transmission path from Bowmanville, Ont., Canada, to Medford, Mass.) Note also mean curves.

maxima in these two records is considered of interest and importance. It will be noted that the time of maximum sky wave for records in both cases lags totality by about twenty minutes. The observations of WCSH are in rather striking accord with the more extensive records taken in the broadcast band during the 1925 eclipse[5] despite the fact that the former eclipse occurred in the morning before the night conditions had wholly given way to normal day transmission, while the 1932 eclipse came in the middle of the afternoon.

(*c*) *Observations on GBR*

Observations on GBR, Rugby, England, operating on a frequency of 16.1 kilocycles were also attempted, using the automatic recording

equipment constructed last year by funds provided from a grant from the National Research Council. No evidence of any conclusive eclipse effect could, however, be found on this record. The indicated results of these observations may hence be considered as negative, but the precision of the record is not sufficient to disclose small changes due to the rapidly rising noise level and the relatively weak field intensity recorded from this station during the period of totality. During the 1925 eclipse, Austin made measurements at Washington on 2XS, Rocky Point, N. Y., operating on a frequency of 57 kilocycles, and a

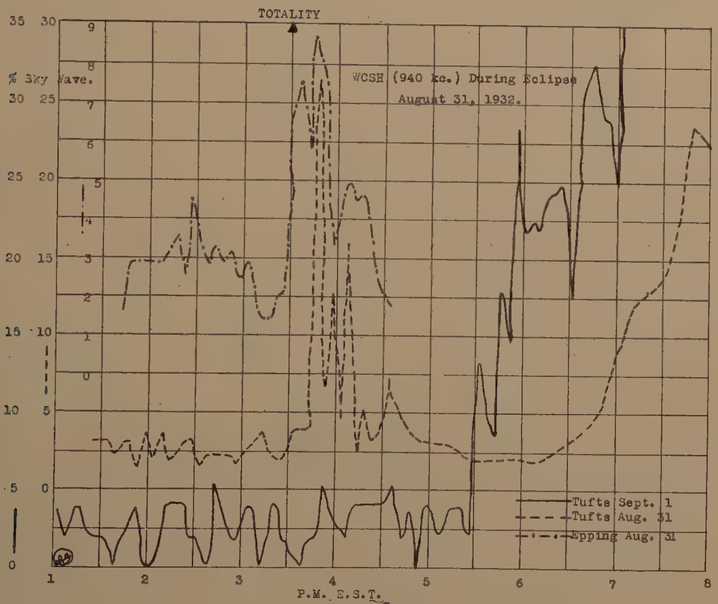


Fig. 12—Sky wave received from WCSH (940 kilocycles) during the afternoon of August 31, 1932.

well-defined eclipse effect was obtained, similar to that found in the broadcast band,[5] but here the low-frequency transmitter was within the path of totality, and also the stronger signals made smaller percentage differences observable with satisfactory precision.

A description of a directional antenna system for limiting static in these observations is described in another publication. Despite the gain thus secured, however, the rapid increase in noise level was so much greater than any signal change observable that no positive evidence for an eclipse effect could be deduced. It is believed that the rapid increase in noise level observed on all the frequencies observed was a true eclipse effect, but this evidence is not considered conclusive

in view of the normally high afternoon static levels frequently en- countered in August.

IV. Examination and Comparison of Results Obtained from Eclipse Observations

The writers attribute the virtual height maxima before and after totality on 3492.5 and 4550 kilocycles to be an abnormally large ratio of virtual-to-true height associated with the layer conditions at this time. Such an effect may be due to changes in ionization distribution in the F region itself, including, perhaps, thermal phenomena and double refraction effects, or to the effects produced by a reduced group velocity

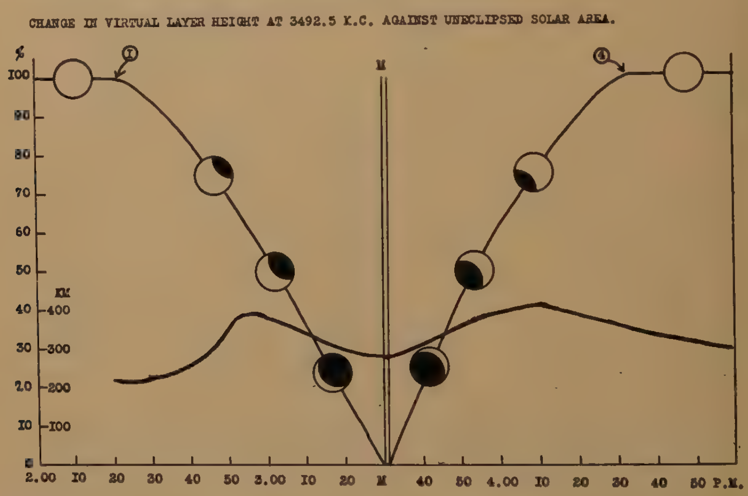


Fig. 13—Comparison of percentage totality with virtual height changes.

in transit through the E region of ionization to and from the F layer which would result in a greater group retardation, and hence a higher virtual height for the layer.[7] It will be noted that the sunset effect exhibits likewise a much reduced rising effect of the same type as that observed during the eclipse; i.e., a rise followed by a fall of the layer during the late afternoon after the transition from the E (100 kilometer region) to the F (200- to 400-kilometer region, reflection. No E-layer reflections were observed early on the afternoon of the eclipse, with the available receiving set gain, but it is considered proba- ble that the ionization in this region was not far from that sufficien

[7] Gilliland, Kenrick, and Norton, "Investigation of Kennelly-Heavisid layer heights for frequencies between 1600 and 8560 kilocycles per second, *Burea of Standards Journal of Research*, vol. 7, no. 6, pp. 1083–1104; December, (1931)

to return the energy, and weak reflections might have been found if greater set gain had been employed.

It will be noted that in the case of the 4550- and 3492.5-kilocycle curves, the phenomena are nearly, if not quite, symmetric in time about totality. It is not necessary to invoke "corpuscular" or other nonoptical eclipses to account for the times of the layer changes shown by the records; Fig. 13 clearly indicates that these variations lie well within the period of the real eclipse. For example, the twin peaks of the 3492.5-kilocycle record occur at times when approximately half the solar disk is obscured, and therefore at times when the sun's radiation has been halved.

However, in the case of the 1640-kilocycle observations the layers only appear after totality, and the E-to-F-layer transition is about one-half hour delayed from totality. Considerable fading in and out of the layers is noted, however, and it is not improbable that higher set gain might have shown effects earlier. The temporary appearance of the F layer on 1640 kilocycles at 4 P.M. (a normal late sunset effect) is considered as probably due to the eclipse. In this connection, it is interesting to note that the time of appearance of the layers corresponds closely with the time of maximum sky wave in the case of the 940-kilocycle observations.

An interpretation of the phenomena of importance in causing changes in the effective height of the Kennelly-Heaviside layer will be much enhanced when a series of records extending over some months or years is available. Such a series is in progress at Tufts College.

V. Acknowledgments

While it is almost impossible to acknowledge in detail all of the assistance which was accorded during the observations described, the authors wish to express their grateful appreciation to the numerous organizations and individuals whose cordial coöperation and aid made the results outlined in this paper possible.

Apparatus for the Kennelly-Heaviside Layer observations at Seabrook Beach, New Hampshire, was provided with the aid of a grant from the Rumford Fund, administered by the American Academy of Arts and Sciences.

Thanks are also expressed to the Naval Research Laboratory, the Bureau of Engineering, and the Portsmouth Navy Yard, who were most generous in their coöperation and furnished a transmitter set-up at Portsmouth.

The Naval Research Laboratory also assisted in the construction of the recorder equipment utilized at Seabrook Breach, New Hamp-

shire, and loaned further equipment for use at Tufts College during the eclipse observations.

The authors also express thanks to Tufts College and its personnel for the loan of the laboratory equipment employed and the use of the recorders located there for the field intensity measurements. Sincere thanks and appreciation are also due to the Short Wave and Television Laboratories, for their cordial coöperation in furnishing the pulse transmissions from Boston and for substantial loans of equipment for the Seabrook Beach, N. H., measurements.

Thanks are also due to Mr. J. Brodie Smith and the New Hampshire Gas and Electric Company for their coöperation in modifying and extending the periods at which their system was synchronized with the Boston Edison Company, so as to permit automatic recording of the Boston pulse transmitter at Seabrook Beach, N. H.

Many thanks are also due numerous individuals for generous donations of their personal time to assist in the work, in particular to Mr. E. C. Remick of the Portsmouth Navy Yard, who assembled the equipment there and monitored its operation, and to Mr. T. L. Robinson of Tufts College, who adjusted and monitored the equipment at Tufts College during the eclipse and who also assisted in the preparations at Seabrook Beach. Mr. Joseph General and Mr. G. A. Sargeant were also of much assistance in the work at Seabrook Beach, where they assisted in the observations.

Sincere thanks are also due to Mr. W. A. Shane and members of his staff for the great extensions of the schedules of VE9GW during the week of the eclipse, which permitted the curves shown for that station to be derived.

Proceedings of the Institute of Radio Engineers
Volume 21, Number 4 *April, 1933*

OBSERVATIONS IN TRANSMISSION DURING THE SOLAR ECLIPSE OF AUGUST 31, 1932*

By
John R. Martin and S. W. McCuskey
(Case School of Applied Science, Cleveland, Ohio)

Summary—*This paper is a report of the result of tests on transmission during the solar eclipse of August 31, 1932. Signals in the 7500-kilocycle band were transmitted from a point in the path of totality and were recorded in Cleveland, Ohio. The records show a slow rise in level until a few minutes before totality when a sharp increase was observed. At totality the signals suddenly dropped to a very low level, then increased slowly until the end of the eclipse, when a second rise in intensity took place. This peak continued for several minutes and then fell to the normal level.*

THE solar eclipse of August 31, 1932, provided an exceptional opportunity for the study of the effect of such phenomena on normal radio transmission and reception, and to provide data for a study of the properties of the ionized regions of the upper atmosphere. Unfortunately, several phases of this study were made quite difficult, due to the time and location of the eclipse path. This was especially true of observations of the corpuscular eclipse which was predicted over a band extending some 4000 miles eastward of and two hours previous to the optical eclipse.[1] Early reports seem to indicate the absence of an effect attributable to neutral particles issuing from the sun, while observers in or near the path of optical totality apparently obtain indications of the activity of ultra-violet light in ionizing the earth's atmosphere.[2]

This paper is a report of a coöperative program of radio transmission and reception conducted during the eclipse by the Warner and Swasey Observatory and the Department of Electrical Engineering, both of Case School of Applied Science. Transmitting equipment was established at Douglas Hill, Maine, in the path of totality, and receiving equipment with provision for continuous recording of signals installed at Cleveland, Ohio. After a comparison of daylight communication on both 3575 and 7150 kilocycles, it was decided to use the latter frequency. The distance from Douglas Hill to Cleveland is approximately 600 miles, making a counterclockwise angle of 80 degrees to the eclipse path. (See Fig. 1.)

* Decimal classification: R113.55. Original manuscript received by the Institute, November 18, 1932. Presented before Cleveland Section, November 18, 1932.

[1] Chapman, Monthly Notices of the R.A.S., 92, March 5, (1932).
[2] *Nature*, vol. 130, p. 3280; September 10, (1932).

Apparatus

The transmitter presents no unusual features, being the regular equipment of the Warner and Swasey Observatory for operation in the amateur channels. It consisted of a crystal oscillator at a frequency of 3575 kilocycles, energizing a buffer amplifier, frequency doubler, and power amplifier. The tubes used in sequence are, a type 210, type 865, type 203-A, and type 860. The power into the last stage was approximately 200 watts. The radiating system consisted of an antenna 134 feet long energized by a parallel tuned radio-frequency line 40 feet

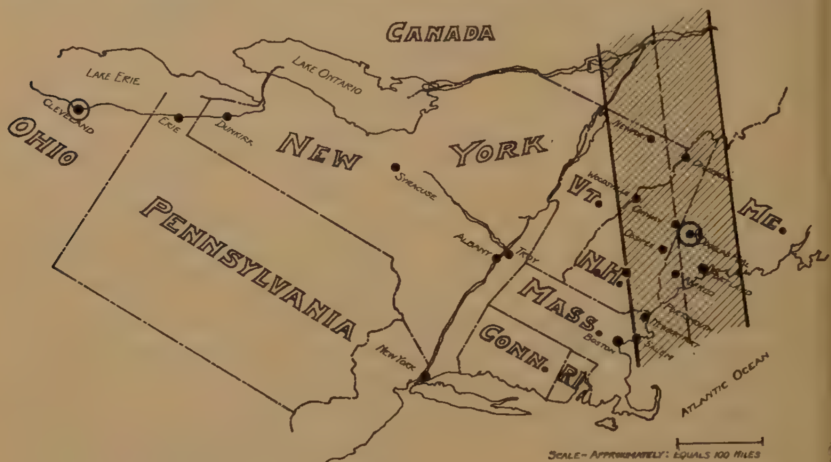


Fig. 1

long. During the tests a constant feeder current, and constant plate current were carefully maintained. Very little difficulty was experienced with the transmitter except for a slight drift in frequency due to the absence of temperature control of the quartz crystal. The absence of wind during the eclipse precluded signal variations due to a swinging antenna.

In choosing the receiving equipment it was felt that reliability of operation was the most important factor to be considered. The short time interval of totality (96 seconds) and the irregularities of transmission at such low powers and high frequencies made it imperative that reliable operation be secured, even at the expense of features which might be of some convenience. Accordingly, the simplest set-up consistent with reliable operation was used. Fig. 2 shows a block diagram of the general arrangements. The output of the receiver operated an automatic recorder through a vacuum tube voltmeter, while a volume indicator was also provided to give visual readings in addition

to the recorded signal variation. In order to check the stability of the receiver during the tests and for calibration purposes, a signal generator feeding through a dummy antenna could also be connected to the receiver.

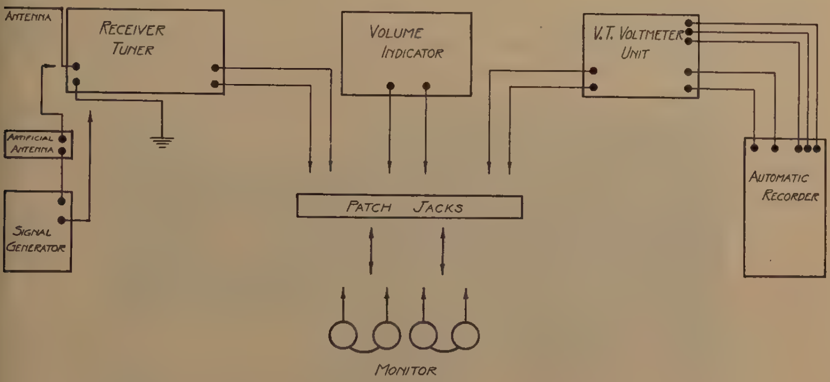


Fig. 2

The automatic recorder used in recording the variations in signal intensity was especially designed for these tests through the courtesy of the Leeds and Northrup Company. It employed a 2000-ohm gal-

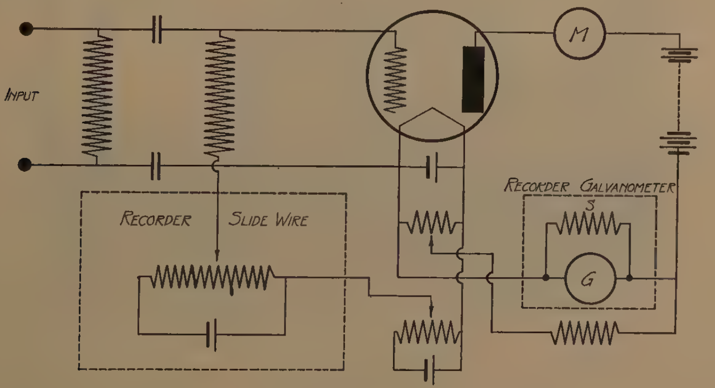


Fig. 3

vanometer and a 600-ohm slide wire. An unusually high paper speed of 24 inches per hour was provided through special gears by a synchronous motor. Signal intensity readings were made once each second.

This recording mechanism was connected to the receiver through a slide-back type of vacuum tube voltmeter as indicated in Fig. 3. The recorder galvanometer was connected in the plate circuit, while the

slide wire controlled the bias of the grid. A copper-oxide rectifier was also provided as alternate equipment, but was not used for the final tests because of lower sensitivity, although it provided somewhat more stable operation.

The receiver was chosen with the fundamental factor in mind of reliability. It was a National type SW 3, and preliminary tests showed

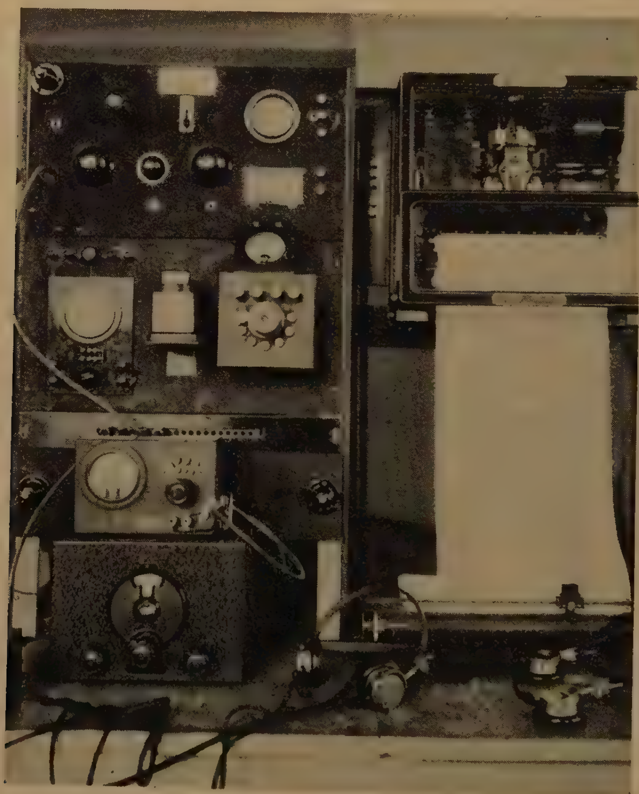


Fig. 4

it to give satisfactory stability of operation and signal strength. It consisted of one-stage radio-frequency amplification, regenerative detector, and one transformer coupled audio stage. Although checked throughout the tests by the signal generator it was not necessary to disturb the operating controls at any time to maintain uniform contact. The volume indicator used for visual observations was a copper-oxide voltmeter of the usual type. The entire receiving and recording equipment is shown in the photograph, Fig. 4.

Observing Program

The test period began at 10 A.M. E.S.T., August 31, and continued without interruption until 5:15 P.M. E.S.T. Continuous signals of five minutes duration were recorded at intervals of five minutes. These alternate five-minute signal-silence periods continued until 3 o'clock. From 3 o'clock to 3:40 a steady signal was maintained without break, and after this period the transmission at five-minute intervals was resumed until the end of the test. The receiver was tuned originally to about a 500-cycle hetrodyne, and this adjustment maintained throughout. The automatic recorder was in continuous operation during the test period, and in addition to this record, readings were made of the volume indicator at regular intervals to supplement the recorder.

Results

In Figs. 5 and 6 are shown the relative changes in signal intensity as recorded in Cleveland. The record of the automatic recorder, Fig. 5, includes, of course, a record of all disturbances impressed on the receiving antenna such as interference from other transmitters, atmospherics, etc., as well as the test signal. However, since a careful log was kept during the tests, these known effects can be disregarded. The solid line joining the group centers indicates the mean trend of the intensity with these effects considered. The broken solid line at the bottom of Fig. 5 indicates the intervals in which the transmitter was being keyed. In Fig. 6 the readings of the volume indicator are plotted throughout the test period. The dotted portions of the first part of this curve are due to severe local power interference which masked the signals during these intervals. It will be noticed that the agreement between the visual and the automatic recorded signals is quite good.

The records show a more or less constant transmission level from the beginning of the tests until the beginning of the eclipse. After first contact there was a very gradual increase in intensity until shortly before second contact, when the signals rose to an abnormally high value, continuing at this level until second contact, when there was a sudden fall of intensity to a very low value, considerably below the normal level. During this interval the signals were completely lost and were not received again until several minutes had elapsed. It may be noted that during this interval interfering signals from the third and fourth districts were received at high levels, a condition which is not normal for Cleveland during this time of day. The test signals rose very slowly, at about the same rate as at the beginning of the eclipse until just before fourth contact, when there was a second abrupt rise in intensity to about the same value as the first. This condition prevailed for several minutes and then dropped gradually to the normal level for this time of day.

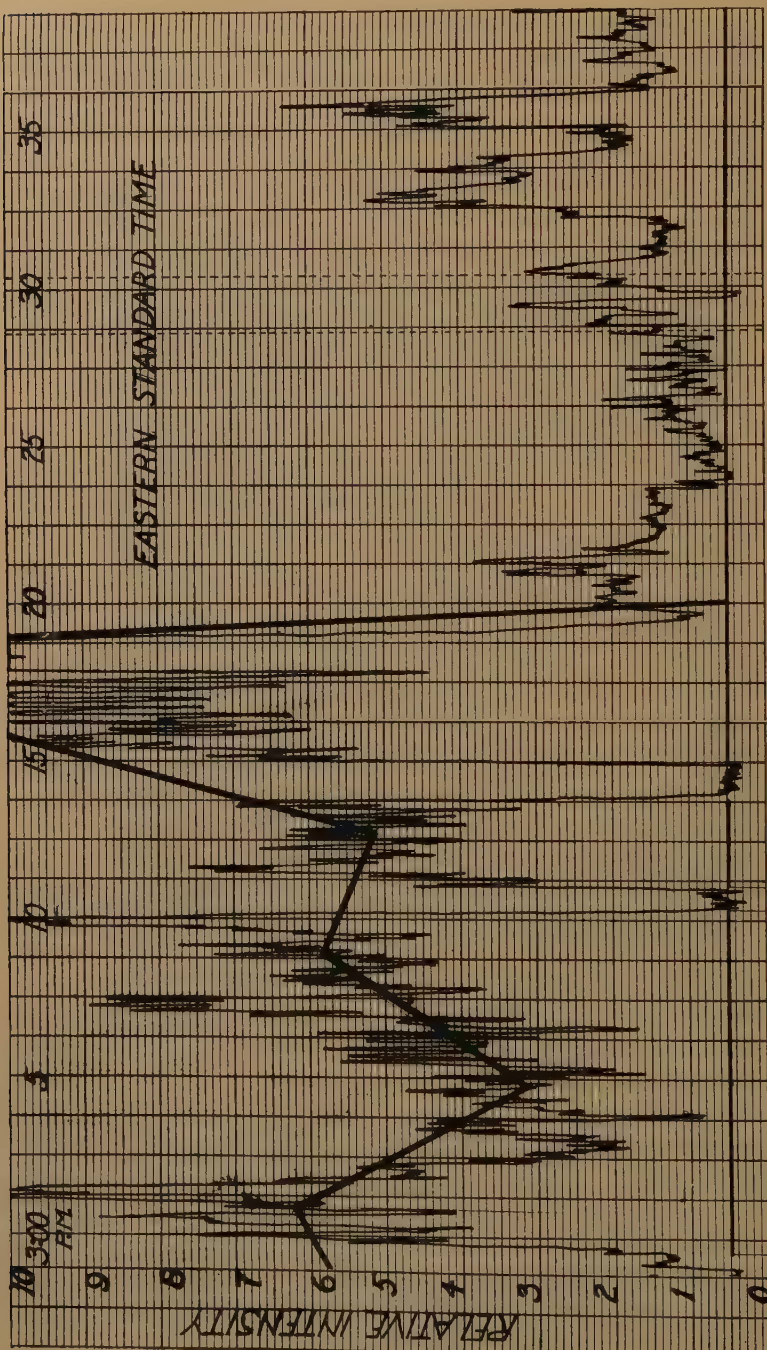
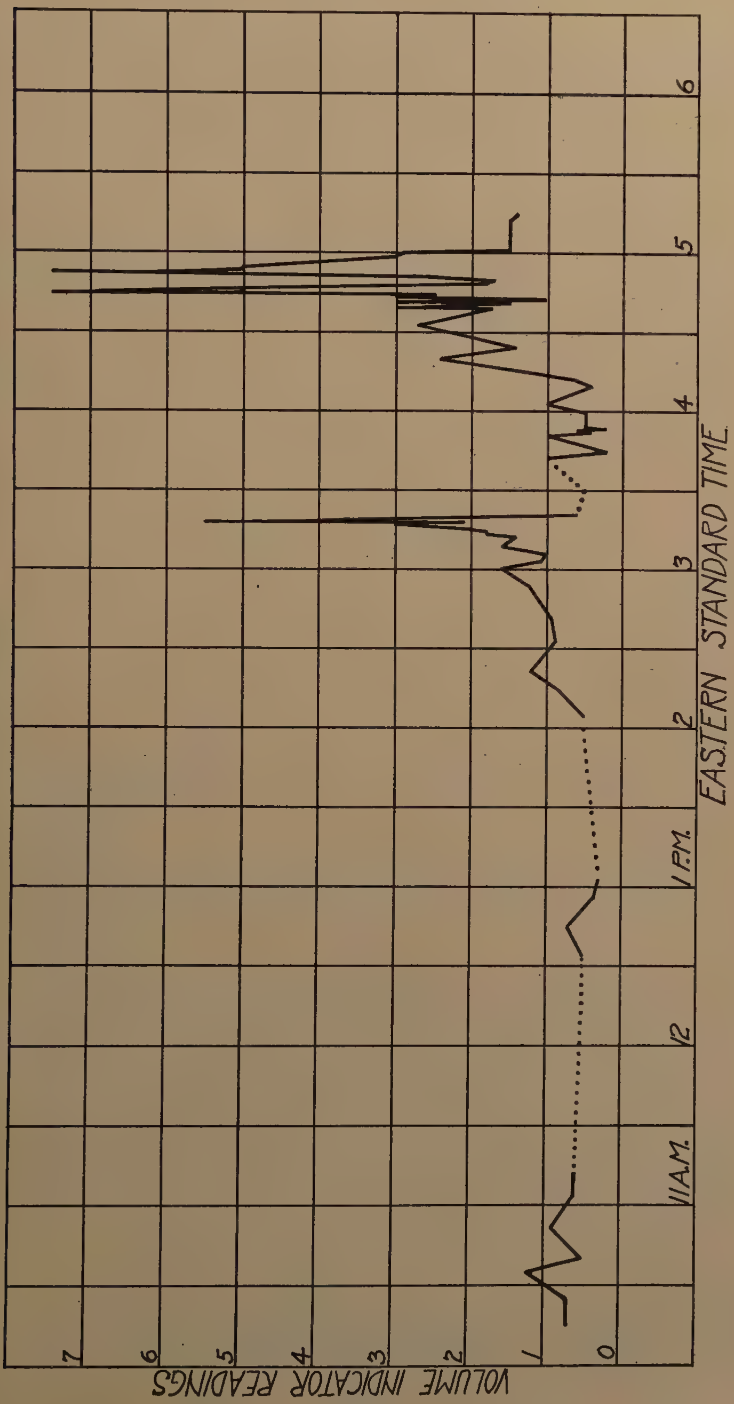


Fig. 5—Continuous record of transmission from Douglas Hill, Maine, as received at Cleveland, Ohio. The beginning of totality at 3:28:41 and its end at 3:30:19 at Douglas Hill are indicated by the vertical dotted lines.



VOLUME INDICATOR READINGS
0
1
2
3
4
5
6
7
EASTERN STANDARD TIME
11 A.M.
12
1 P.M.
2
3
4
5
6

Fig. 6

Proceedings of the Institute of Radio Engineers
Volume 21, Number 4 *April, 1933*

EXPERIMENTS ON ELECTROMAGNETIC SHIELDING AT FREQUENCIES BETWEEN ONE AND THIRTY KILOCYCLES*

By
Walter Lyons
(Wells-Gardner and Company, Chicago, Illinois)

Summary—*This paper describes a method used in measuring the ratio of magnetic field intensities within conducting cylindrical and spherical shells to that outside, values being given for various frequencies between 1000 and 30,000 cycles per second of the exciting field and various lengths and radii. A theoretical derivation of a shielding formula is given for a thin spherical shell and a cylindrical one of infinite length. Satisfactory agreement between theory and observation is found in the case of the sphere and in cylinders of lengths greater than their diameters.*

I. Introduction

The following investigations were carried on in the communications laboratory of the engineering department at McGill University under the direction of Dr. F. S. Howes, of the staff of the faculty of engineering, and Professor Louis V. King, of the physics department. This work was begun in October, 1930, and completed in April, 1932.

The purpose of this research is to offer experimental evidence in support of shielding formulas derived by Dr. King, and to furnish data on the shielding effect of hollow cylindrical conductors in oscillating magnetic fields, which may serve as a guide in the proper design of shielding apparatus against high-frequency electromagnetic fields. Recently the use of high-frequency measuring equipment and development of radio circuits have required the shielding of various pieces of apparatus to an almost perfect degree. The usual form that the shielding is required to take is that of a more or less cylindrical shape or of sheets or plates. Since the shielding effect of plates has been rather fully covered by John H. Morecroft and Alva Turner,[1] the subject matter of this paper will confine itself to hollow cylindrical shells.

Experiments of R. H. Barfield[2] in 1923 furnish quantitative data on the screening effect of large iron containers and mesh screens. In this paper methods of shielding either the magnetic or electric intensities alone are discussed.

* Decimal classification: R201.5. Original manuscript received by the Institute, October 24, 1932.

[1] John H. Morecroft and Alva Turner, "The shielding of electric and magnetic fields," Proc. I.R.E., vol. 13, p. 477; August, (1925).

[2] *Jour. I.E.E.* (London), vol. 62, p. 249, (1924).

In 1882 Lord Rayleigh[3] found that the induction between two coils was decreased greatly when a copper sheet was placed between them. The experiment was qualitative, no quantitative values of shielding being given. In the paper Lord Rayleigh quotes Maxwell,[4] who showed in 1871 that a perfectly conducting sheet acts as a barrier to magnetic force.

A theoretical and quantitative consideration of the shielding effect of spherical shells was given by Sir James Larmor[5] in 1884. The treatment here is for the case of low-frequency fields.

In 1930 Professor King[6] derived formulas for the shielding effect of infinitely long cylinders and hollow spheres of finite wall thickness and diameter, applicable to all frequencies.

II. Theory

1. *Nomenclature*

ρ = specific resistance in electromagnetic units
d = thickness of shell in centimeters
a = mean radius in centimeters
f = frequency in cycles per second
$\omega = 2\pi f$
i = current density
$I = i \times d$ = current per unit length
$H_i = |H_i| \sin(\omega t - \beta)$ = magnetic intensity inside shell
$H_0 = |H_0| \sin \omega t$ = magnetic intensity outside shell
c = eddy current or induction constant
$c^2 = \rho/8\pi^2 f$
dz = an element of cylinder length
E = electric field tending to force current around circles perpendicular to the exciting field

2. *Shielding Ratio for Thin Cylindrical Shell of Infinite Length*

The method of attacking the following problem was indicated by Professor King.

Let us consider a hollow shell of wall thickness d, small compared to the mean radius a. The frequency f considered is so low that the induced current density i in the shell is, approximately, uniform.

For simplicity of calculation the exciting magnetic field H_0 is supposed to be parallel to the axis of the cylinder. According to Faraday's law, an electric field is set up tending to cause current to flow in circles around the cylinder. Owing to a phase difference of 90 degrees the current, thus induced, opposes the external field, giving rise to a certain degree of "shielding."

[3] *Phil. Mag.*, vol. 13, p. 344; May, (1882).
[4] "Electricity and Magnetism," vol. 2.
[5] *Phil. Mag.*, vol. 17, p. 5; January, (1884).
[6] Louis V. King, *Phil. Mag.*, ser. 7, vol. 15, p. 201; February, (1933).

At high frequencies the induced current is not uniform, but tends to concentrate on the outer surface (skin effect) in the well-known manner, and, in general, the shielding effect is a combination of these two.

In order to determine the relation between the internal and external fields, we take a unit pole along a closed rectangular circuit of length dz, (1) just inside the shell, (2) through the shell, (3) just outside the shell, and (4) back through the shell. Since the field is parallel to the side dz of the circuit, it is obvious that the work contributed by the parts (2)

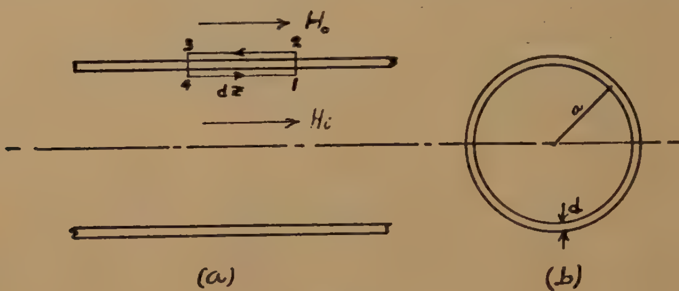


Fig. 1

and (4) is zero. The remainder of the circuit contributes $(H_i - H_0)dz$, and so by Ampere's law,

$$(H_i - H_0)dz = 4\pi I dz \tag{1}$$

or,

$$(H_i - H_0) = 4\pi I$$

where I = the current per unit length; i.e., $I = id$. The induction through the section dz of area πa^2 is

$$\phi = \pi a^2 |H_i| \sin(\omega t - \beta). \tag{2}$$

By Faraday's law the electromotive force around the section is equal to the work done in taking a unit charge around the circuit $2\pi a$; i.e.,

$$2\pi a E = -\frac{d\phi}{dt}.$$

By Ohm's law

$$i = \frac{E}{\rho}, \text{ and since } I = i \times d \times 1\text{cm},$$

then,

$$I = \frac{-d}{2\pi a \rho}\frac{d\phi}{dt} = -\frac{\omega a d}{2\rho}|H_i| \cos(\omega t - \beta).$$

Substituting for I in (1) we have the following relation which must hold for all instants of time.

$$|H_i| \sin(\omega t - \beta) - |H_0| \sin\omega t = -\frac{2\pi\omega a d}{\rho} |H_i| \cos(\omega t - \beta).$$

Equating the coefficients of sin ωt and cos ωt, or more simply, writing successively $\omega t = 0$, and $\omega t = \beta$, we find at once,

$$\tan\beta = \frac{2\pi\omega a d}{\rho} = \frac{1}{2}\frac{ad}{C^2} \tag{3}$$

and,

$$|H_0| \sin\beta = H_i \tan\beta$$

or,

$$\frac{|H_i|}{|H_0|} = \cos\beta. \tag{4}$$

3. *Shielding Ratio for Thin Spherical Shell*

We now examine the case of a thin spherical shell, radius, a, and wall thickness, d, in a uniform alternating field, H_0. Inside and outside the shell, the field may be completely specified by the magnetic potentials Ω_i and Ω_0.

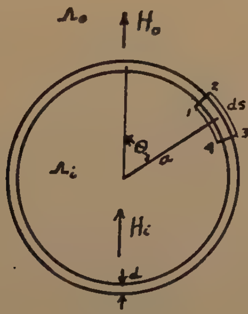


Fig. 2

Referring to Fig. 2, calculate the work done in taking a unit pole around the closed circuit (1,2,3,4) of length ds and side dn.

At the boundary between the two media we apply Gauss' Theorem to a thin volume whose thickness is dn and area S' just inside, and S just outside the spherical surface. In the limit when S and S' are infinitely close, the contribution of the edge to the surface integral

$$\int N ds = 0.$$

Since there are no free magnetic poles inside the volume, whose opposite sides are of area S and S' we have,

$$SH_n - S'H_n' = 0 \text{ where } H_n \text{ and } H_n'$$

are the normal components of the external and internal magnetic fields.

Ultimately since $S = S'$ for an infinitely thin shell, we have the usual boundary condition $H_n = H_n'$, establishing the continuity of the normal component of field through the shell.

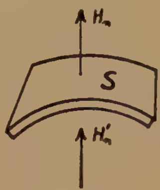


Fig. 3

In the present problem the normal component

$$H_n = \left(\frac{\partial \Omega_0}{\partial r}\right)_{r=a}$$

and,

$$H_n' = \left(\frac{\partial \Omega_i}{\partial r}\right)_{r=a}$$

so that,

$$\left(\frac{\partial \Omega_0}{\partial r}\right)_{r=a} = \left(\frac{\partial \Omega_i}{\partial r}\right)_{r=a}. \tag{1}$$

The tangential components of the external and internal fields, respectively, are $1/r\ \partial\Omega_0/\partial\theta$ and $1/r\ \partial\Omega_i/\partial\theta$.

Calculating the work done along the circuit (1,2,3,4) as before, Ampere's formula gives, after dividing by ds

$$\left[\frac{1}{r}\frac{\partial \Omega_i}{\partial \theta} - \frac{1}{r}\frac{\partial \Omega_0}{\partial \theta}\right] = 4\pi i d. \tag{2}$$

These potentials Ω_0 and Ω_i satisfy Laplace's equations, $\nabla^2\Omega = 0$. The appropriate solutions are

$$\Omega_0 = H_0 r \cos\theta + \frac{A\cos\theta}{r^2}$$

and,

$$\Omega_i = H_i r \cos\theta.$$

The expression for Ω_0 when $r \to \infty$ gives the potential of a uniform field H_0. The solution for Ω_i is the only one which enables the boundary conditions to be satisfied for all values of θ.

Inserting the values of $\partial\Omega_i/\partial\theta$ and $\partial\Omega_0/\partial\theta$ at $r=a$ in (2) we obtain

$$\left[H_0 + \frac{A}{a^3} - H_i\right] \sin\theta = -4\pi i d. \tag{3}$$

From (1) we find

$$H_0 - \frac{2A}{a^3} = H_i$$

or,

$$\frac{A}{a^3} = \frac{H_0 - Hi}{2}$$

and by substitution (3) becomes

$$\frac{3}{2}[H_0 - H_i] \sin\theta = -4\pi i d. \tag{4}$$

By Ohm's law,

$$i = \frac{E}{\rho}. \tag{5}$$

By Faraday's law the electromotive force around circuit = work done in taking unit charge around circuit $2\pi a \sin\theta$

$$\text{i.e., } (2\pi a \sin\theta) E = -\frac{d\phi}{dt}. \tag{6}$$

We at once see that $\phi = H_i \times$ (area of section of radius $2\pi a \sin\theta$) or,

$$\phi = \pi a^2 \sin^2\theta \, |H_i| \sin(\omega t - \alpha).$$

Thus differentiating,

$$\frac{d\phi}{dt} = \omega\pi a^2 \sin^2\theta \, |H_i| \cos(\omega t - \alpha)$$

thus according to (6),

$$E = -\frac{\omega a \sin\theta}{2} |H_i| \cos(\omega t - \alpha)$$

and (5) gives,

$$i = -\frac{\omega a \sin\theta}{2\rho} |H_i| \cos(\omega t - \alpha).$$

The occurrence of the factor sin θ, in the above expression enables us to satisfy condition (4) for all values of θ, and thus obtain the required relation between H_i and H_0 in the form

$$|H_0| \sin \omega t - |H_i| \sin (\omega t - \alpha) = \frac{4\pi\omega a d}{3\rho} |H_i| \cos (\omega t - \alpha).$$

Since this equation holds for all instants of time we may equate the coefficients of sin ωt and cos ωt, or, more simply, write successively $\omega t = 0$ and $\omega t = \alpha$ and obtain at once

$$\tan \alpha = \frac{4\pi\omega a d}{3\rho} = \frac{1}{3} \frac{ad}{C^2}, \tag{7}$$

and,

$$\frac{|H_i|}{|H_0|} = \cos \alpha. \tag{8}$$

The results found above for the theoretical attenuation factor agree exactly with the low-frequency approximation of the King formula. It is, therefore, reasonable to expect the above method correct for the assumption made.

The exact formula is as follows:

$$\frac{H_i}{H_0} = \frac{1}{\cosh kd + Ska \sinh kd}.$$

where S is the shape factor. ($S = \frac{1}{2}$ in the case of the cylindrical shell, and $S = \frac{1}{3}$ in the case of the spherical shell.)

$$k^2 = \frac{j}{C^2} \text{ where } j = \sqrt{-1}.$$

The absolute value of the field intensity ratio is given very simply by,

$$\frac{H_i}{H_0} = \frac{C/Sa}{(\sinh^2 x + \sin^2 x)^{1/2}},$$

where,

$$x = \frac{d}{C\sqrt{2}}.$$

III. Apparatus

The arrangement of apparatus used in the experimental work is shown in Fig. 4. On the left is found the oscillator and amplifier which is connected to a pair of Helmholtz coils tuned to the desired frequency by a condenser. In the center of the Helmholtz coil arrangement there

are two search coils, one large and one much smaller, each fixed on an arm so that they may rotate freely about the center shaft. The drum to which they are connected is so fixed that the coil occupying the lower position is connected through two leads (shielded by the shaft), to the vacuum tube voltmeter found on the extreme right of the figure.

The Helmholtz coils are fifteen inches in diameter and one and one-half inches wide wound with 104 turns each of Litz wire having the direct-current conductance of No. 14 copper wire. Their diameter was made large in order to secure as large a field of uniform magnetic flux as possible and adequate for the purpose, bearing in mind the possible distortion of the field due to the shielding cylinder located in it. A

Fig. 4

great deal of precision is unnecessary here since both search coils occupy very nearly the same position in the field when connected in circuit.

The reason for using two search coils, one small, the other larger, with the larger coil carrying the shield only, is obvious from the following symbolic considerations:

I = current in the field coils
H_1 = magnetic field small coil in circuit
H_2 = magnetic field large coil in circuit
E_1 = voltage at the terminals of the small search coil
E_2 = voltage at the terminals of the larger search coil
N_1 = number of turns on the small search coil
N_2 = number of turns on the larger search coil
A_1 = cross-sectional or turn area of the small search coil
A_2 = cross-sectional or turn area of the larger search coil
K = attenuation factor

where $K=1$, with no shield and $K<1$, inside shield.

Let,

$$E \propto HNAK$$

$$\frac{E_2}{E_1} = \frac{H_2N_2A_2K}{H_1N_1A_1} = \frac{I_2N_2A_2K}{I_1N_1A_1}$$

$$K = \frac{E_2}{E_1}\,\frac{I_1}{I_2}\,\frac{N_1A_1}{N_2A_2}\,.$$

Thus if the search coils are so arranged that $N_1A_1 : N_2A_2 \div K$, and since the current in the field coils does not vary over small intervals of time, E_2 will be of the same order as E_1 and can therefore be read on the same voltmeter scale.

The larger search coil was designed after the following consideration in order that the voltage, as measured at the end of the leads, would be very nearly that of the coil terminals.

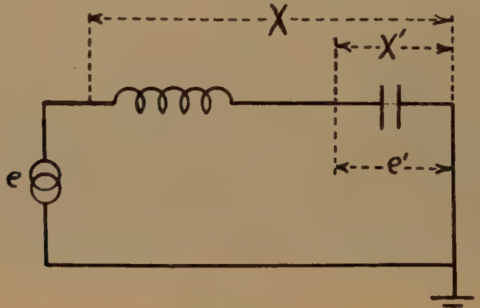


Fig. 5

X = reactance of search coil and capacity of leads and voltmeter
X' = reactance of leads and voltmeter

$$X = \omega L - \frac{1}{\omega c}$$

$$X' = -\frac{1}{\omega c}$$

$$\frac{e'}{e} = -\frac{\frac{1}{\omega c}}{\omega L - \frac{1}{\omega c}} = \frac{1}{1 - \omega^2 Lc}$$

Hence, if L is made less than one per cent of $1/\omega^2 c$, e' will equal e within the precision of the experiment.

The circuit of the voltmeter is adjusted until the plate current is three microamperes in order to obtain rectification on the square-law part of the plate-current grid-voltage curve. This three-microampere plate current is then balanced out, the alternating voltage applied

to the grid and the plate current read on a microammeter. The current reading varies directly as the square of the voltage applied to the grid terminal. Before using, the voltmeter was calibrated, using a Weston dynamometer type voltmeter at 60 cycles. Since the input capacity of the screen grid valve is only about four micromicrofarads practically no current is drawn and the frequency calibration is uniform up to very high frequencies.

The oscillator was used to drive two pentode valves in parallel as amplifiers which were connected directly to the tuned field coils.

The large search coil was designed upon considering the capacity of the leads and voltmeter, which were found to be 50 micromicrofarads and after choosing the frequency to be used. This was very important since the amount of power available was very small, only about five watts, therefore requiring as large a search coil as possible within the limitations allowed.

It was impossible to obtain readings at radio frequencies due, in part, to the small number of turns on the primary and secondary coils. Another limitation, in making radio-frequency measurements, arises when King's asymptotic formula, for the shielding ratio at radio frequencies, is considered. The formula for the cylinder is

$$\frac{|H_i|}{|H_0|} = 4\frac{c}{a}e^{-d/c\sqrt{2}}$$

where,

$$\begin{aligned} c^2 &= \frac{\rho}{8\pi^2 f} \\ a &= \text{radius} \\ d &= \text{thickness} \\ \rho &= \text{specific resistance} \\ f &= \text{frequency} \end{aligned} \tag{9}$$

For one of the aluminium cylinders used

$$a = 2.54 \text{ cm};\ d = 2.54 \times 10^{-2} \text{ cm};\ \rho = 3 \times 10^{-6} \text{ ohms}$$
$$= 3000 \text{ e.m.u};\ f = 10^6;\ c = 6.17 \times 10^{-3} \text{ cm};$$
$$c/a = 2.43 \times 10^{-3};\ \frac{d}{c\sqrt{2}} = 2.91;\ e^{-d/c\sqrt{2}} = 0.0550.$$

Formula (9) gives $H_i/H_0 \doteq 5\times10^{-4}$.

With the coil employed $H_0 \doteq 6$ gauss, and in this instance the voltage across the secondary was approximately 18 volts. With the shielding cylinder this voltage is reduced to 10^{-2} volts, which is beyond the sensitivity of the ionization voltmeter. To study shielding at radio frequencies with the available power a voltage sensitivity of at least 10^{-4} volts is required.

In an attempt to measure this small ratio, experiment indicated a value less than 10^{-3} as indicated theoretically by the result given above.

The apparatus was grounded by soldering separate leads to each section of the brass shield tubes and voltmeter ground and tying a lead to the shielding cylinder. All the leads were brought to one common point which was earthed. This is diagrammatically illustrated in Fig. 6.

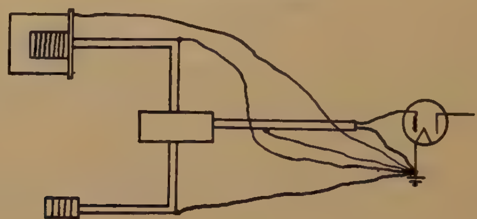


Fig. 6

IV. Procedure

At the first an attempt was made to measure the shielding effect at a frequency of 1000 kilocycles. Since the effect of shielding was of the order of 99.9 per cent and higher, no reading of voltage generated in the shielded coil could be made with the apparatus used, the lowest measurable voltage being 0.1 of a volt.[7] The limitations due to the apparatus used, were a maximum power of only five watts, field coils of of only thirteen turns each and a shielded search coil of only six turns on a one and one-quarter-inch form. The size of the field coils was limited in that the tuned circuit impedance L/rC had to be so adjusted that the maximum power output could be obtained from the oscillator amplifier. The number of turns on the search coil was limited by the consideration mentioned under "Apparatus."

Since no higher power was obtainable the only solutions to the problem lay in either introducing amplification between the search coils and voltmeter, or the lowering of the frequency to be used. Amplification was tried but found to be unsatisfactory due to extraneous pick-up, microphonic effects in the amplifier valves, and unsteady amplification. This led to the necessity of decreasing the frequency, first to 100 kilocycles and finally to 10 kilocycles.

The two search coils were so constructed that their turns area ratio was made equal to 0.0790. The larger coil was fixed with a mounting to support the cylinders.

An examination of the voltmeter calibration curve revealed that the current, measured in microamperes, was directly proportional to

[7] Refer to page 583.

the square of the voltage applied. Therefore, it was unnecessary to convert the microampere reading into volts, and the results of field intensity ratio were arrived at in the following manner.

$$|H_i|/|H_0| = K = 0.0790\sqrt{\frac{\mu I_i}{\mu I_0}}$$

where,

$|H_i|$ = field intensity inside the shield

$|H_0|$ = field intensity outside the shield

μI_0 = scale reading for voltage across unshielded coil

μI_i = scale reading for voltage across shielded coil.

Measurements of field intensity ratios were taken using aluminum cylinders of various lengths, diameters, and thicknesses, at a frequency of 10,000 cycles per second, and, in some cases, the frequency was allowed to vary between 1000 and 30,000 cycles per second. Curves were then plotted for the field intensity ratio against each of the above as variables separately, keeping everything else a constant.

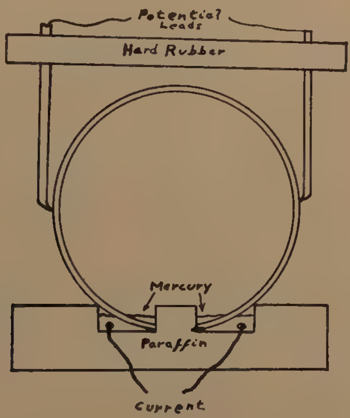


Fig. 7

The theoretical values were calculated by using both low-frequency and high-frequency approximations of Professor King's formula, the low-frequency approximations being plotted since they were found to fit the experimental results more accurately than the high-frequency approximation.

The specific resistance of the cylinders in the direction of the induced currents was measured on a Kelvin double bridge. This was done by first slitting the cylinders lengthwise, the edges thus formed being inserted into mercury-filled troughs to be used as the current

electrodes. The potential electrodes were made up in the form of a pair of sharp pointed dividers. A cross section of the apparatus used is shown in Fig. 7.

Resistance readings were taken for various positions of the potential electrodes along the cylinders and an average found, from which the specific resistance was calculated. Approximately thirty readings were made on each cylinder.

The thickness of the cylinder walls was determined by using a pair of micrometer calipers with a ball anvil. The measurement used was the mean of twenty readings, this value being checked by weighing, and, knowing the density, calculating the thickness.

The diameters of the cylinders were measured with a pair of vernier calipers.

All the above measurements would certainly be relied upon to be within an error of one per cent.

A few sample observations are tabulated below in order to acquaint the reader with the method used in making observations of the shielding effect.

TABLE I

VARIATION OF FREQUENCY

Aluminum cylinder 8.89 cm long, 0.0274 cm thick, 2.64 cm radius. Specific resistance =3260 e.m.u.

f	μI_i	μI_0	Experimental $\frac{\lvert H_i\rvert}{\lvert H_0\rvert}=0.0790\sqrt{\frac{\mu I_i}{\mu I_0}}$	Calculated $\frac{\lvert H_i\rvert}{\lvert H_0\rvert}=\cos a$
30,000	1.10	3.47	4.46 per cent	3.81 per cent
25,000	1.80	4.30	5.11	4.57
20,000	2.89	4.60	6.26	5.70
18,000	3.13	4.20	6.82	6.34
14,000	5.85	4.75	8.95	8.14
10,000	10.15	4.40	12.0	11.35
9,000	6.08	2.10	13.5	12.6
8,000	6.50	1.76	15.0	14.2
7,000	5.47	1.10	17.6	16.1
6,000	8.83	1.35	20.2	18.7
5,000	7.73	0.82	23.9	22.3
4,000	7.10	0.53	28.9	27.5
3,000	34.0	1.59	36.6	35.5
2,500	74.2	2.70	41.5	41.5
2,000	63.0	1.50	51.4	49.6
1,000	19.8	0.20	78.0	75.1

V. Discussion of Results

On examination of the curves plotted, (Figs. 8, 9, 10, and 11) showing the effect of variation of frequency upon shielding effect, we notice an extraordinary agreement between the theoretical and observed results. In the cases of the cylinders the discrepancy which exists is due probably to the lengths being too small for the theory to apply exactly, in addition to experimental errors which may be as much as 5 per cent, due to the limitation in the determination of the physical constants of

the cylinders plus the observational error. The fact that the theoretical curves all lie below the observed bears out the theory for the discrepancy being due to short cylinders. The curves for the variation of length illustrate the effect even more clearly.

The opposite effect is shown in the curves for the sphere, the theoretical lying above the observed. This effect may be due to two things, the distortion of the exciting field and the resulting distortion of the inner field, due to the size of the sphere being comparable to the di-

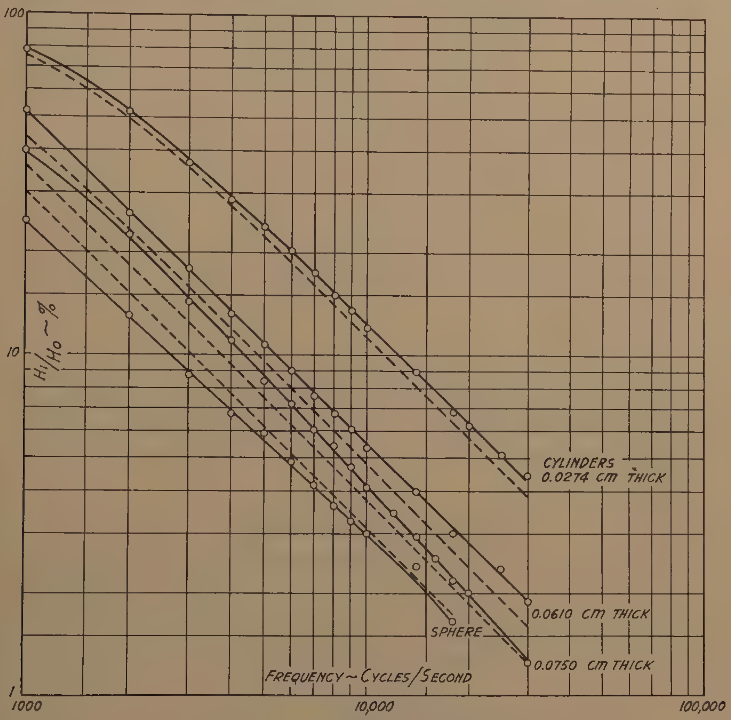


Fig. 8—Variation of frequency.
Cylinders: Aluminum, 8.9 centimeters long, 2.70 centimeters radius.
Sphere: Copper, 7.52 centimeters radius, 0.028 centimeters thick.
Experimental ————————
Theoretical ---------

ameter of the Helmholtz coils and to the presence of a rim used to join the two halves of the sphere in a plan perpendicular to the direction of the exciting field.

In Fig. 9 the effect of the variation of thickness is shown. The difference here, between the theory and observation, is due to the length of the cylinder being too small to be considered adaptable exactly to theory.

The nonuniformity of the curves, Fig. 10, showing the effect of variation of radius, was due to the necessity of having a second independent variable, namely, the thickness of cylinder wall. The only cylinder available for these tests varied in wall thickness as much as 25 per cent, which explains the irregularity; the theoretical curve being calculated from each cylinder, taking into account its individual thick-

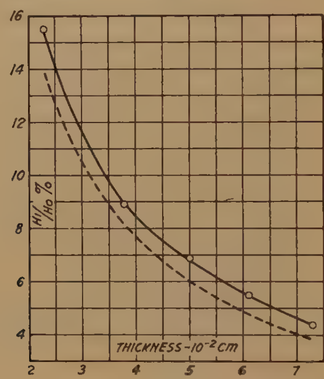


Fig. 9—Variation of thickness.
Cylinders: Aluminum, 8.9 centimeters long, 2.70 centimeters radius.
Frequency = 10,000 cycles.
Experimental ————
Theoretical - - - - - - - - - -

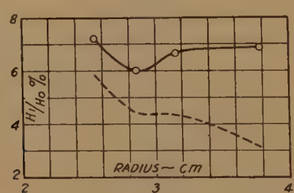


Fig. 10—Variation of radius.
Cylinders: Aluminum, 7.35 centimeters long.
Mean thickness = 0.0562 centimeters.
Frequency = 10,000 cycles.
Experimental ————
Theoretical - - - - - - - - - -

ness. The observed values run parallel to the theoretical until the diameter of the cylinder is of the same order as its length. At this point and for larger diameters the shielding ratio departs from the predicted values, the shielding effect decreasing with increasing radius, which is the reverse of what the theory for a cylinder gives. This phenomenon is also shown in the curves for variation of length, the cylinders depart

ing only slightly from the theoretical values until the length is about equal to the diameter, where a sharp change in the slope occurs, and the formula no longer applies.

The final set of curves illustrates the effect of disks placed over the cylinder ends and the change in shielding due to variation of the length. Thus we see that placing ends on the cylinders serves to increase the shielding only when the length of the open-ended cylinders is decreased below the value which is of the same order as the diameter. This observation is quite reasonable since one would not expect to notice the effect of a thin disk at the end of a long cylinder if we consider as an analogous case the field due to a long solenoid.

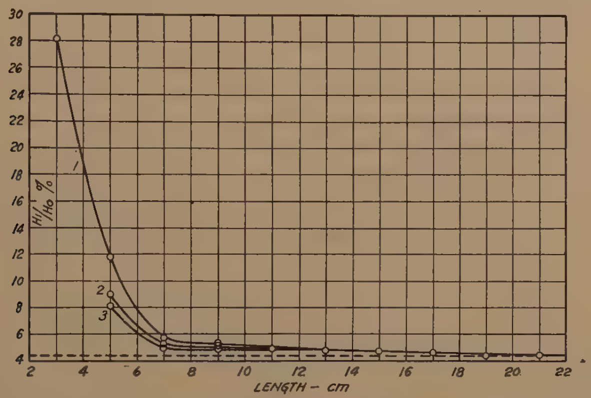


Fig. 11—Variation of length.
Cylinder: Aluminum, 2.70 centimeters radius, 0.0660 centimeters thick.
Frequency = 10,000 cycles.
1. Both ends open
2. One end closed.
3. Both ends closed.
Theoretical -----------

VI. Conclusion

Since the derivations of the formulas by Professor King are rigorous and have been tested in the frequency range of 1000 to 30,000 cycles, we may conclude that the formula will hold for all thicknesses of shell and all frequencies from zero to the low-frequency radio oscillations. The results lead us also to the conclusion that the theory is not applicable to cylinders having diameters of the same order or greater than the length. Furthermore, that within this same range of dimensions only, ends placed on cylinders will increase the shielding effect and render the combination effect applicable to the theoretical investigation of cylinders of greater diameter.

VII. Acknowledgment

Acknowledgment is here made to Professor L. V. King for his guidance and invaluable criticism throughout the work, to Dr. F. S. Howes, under whose direction the research was made, to Dean A. S. Eve, for his encouragement and aid in procuring the necessary apparatus, to Mr. Harold A. Wheeler, who inspired and suggested the investigation, and to Mr. Kenneth A. Evelyn, for his kind assistance in determining the physical constants of the samples tested.

Proceedings of the Institute of Radio Engineers
Volume 21, Number 4 *April, 1933*

GRAPHICAL DETERMINATION OF PERFORMANCE OF PUSH-PULL AUDIO AMPLIFIERS*

By

B. J. Thompson

(Research and Development Laboratory, RCA Radiotron Company, Inc., Harrison, N. J.)

Summary—*Previous methods used for determining graphically the performance of push-pull audio amplifiers are inaccurate because they neglect the coupling between the tubes through the output transformer. A relatively simple method is presented which takes this effect into account. It consists in combining the plate-current—plate-voltage characteristics of the tubes to form a family of composite characteristics. This may be used to determine the performance for any load resistance in the same manner as is done for single tubes. This method is equally applicable to class A or class B conditions.*

It is found that each tube operates into a variable load resistance, which, under optimum conditions, is equal to its internal resistance at every point throughout the cycle.

An experimental verification under a number of operating conditions is presented, showing close agreement between computed and measured values of power output, distortion, and average plate current.

Introduction

IT IS the purpose of this paper to present a simple and accurate method for determining graphically from their static characteristics the performance of vacuum tubes when used in push-pull audio amplifiers.

Considerable attention has been devoted to the determination of the performance of single tube amplifiers;[1] however, the methods developed are not directly applicable to push-pull amplifiers, due to the coupling between the two tubes through the output transformer. In spite of this, it has been customary simply to double the output as determined for a single tube in determining the output of a class A push-pull amplifier, though it has been recognized that the maximum power and optimum load so found do not agree with the experimentally determined values.

A slightly different method has been used for determining the performance of class B push-pull amplifiers,[2] which gives good results only when the plate current at normal voltages is very low.

* Decimal classification: R355.7. Original manuscript received by the Institute, December 1, 1932.

[1] J. C. Warner and A. V. Loughren, Proc. I. R. E., vol. 14, no. 6, p. 735; December, (1926).

[2] L. E. Barton, Proc. I. R. E., vol. 19, no. 7, p. 1131; July, (1931).

Very recently methods have been presented for analyzing class A and class B amplifiers,[3] and a criterion offered for choosing between the two methods in the borderland between class A and class B operation. It is difficult to see how the class A method can offer any advantages over the previous methods, either in accuracy or convenience. Neither the class A method nor the class B method takes account of the coupling between the two tubes.

In view of these difficulties with previous methods of analysis and the widespread use of push-pull audio amplification, it is felt that a simple method for determining accurately the performance of push-pull audio amplifiers operating under class A, class B, or any intermediate conditions, should be of real value.

The Method

Fig. 1 represents a typical push-pull audio amplifier. If the resistances and leakage reactances of the input and output transformers are negligible—in a well-constructed amplifier they are—the grid and

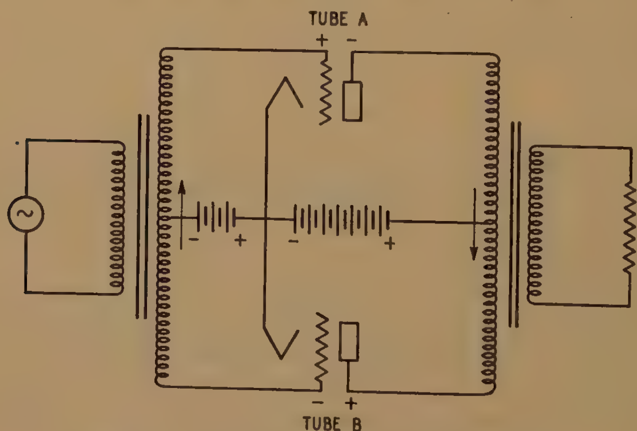


Fig. 1—Typical push-pull audio amplifier.

plate alternating voltages of tube A are exactly equal in magnitude to and 180 degrees out of phase with the corresponding voltages of tube B, while the direct voltages are the same on both tubes. Since the two halves of the primary winding of the output transformer are in mutual opposition, the magnetomotive force produced by the plate current of the two tubes is equal to that which would be produced by a current equal to the difference between the current flowing in tube A and that flowing in tube B, flowing in one half of the primary winding. What is

[3] J. R. Nelson, Proc. I. R. E., vol. 20, no. 11, p. 1763; November, (1932).

desired, then, is a graphical representation of the difference between the currents of the two tubes as a function of plate and grid voltages, taking into account the phase relation between the voltages on the two tubes.

Fig. 2 shows the method for accomplishing this. Plate current is

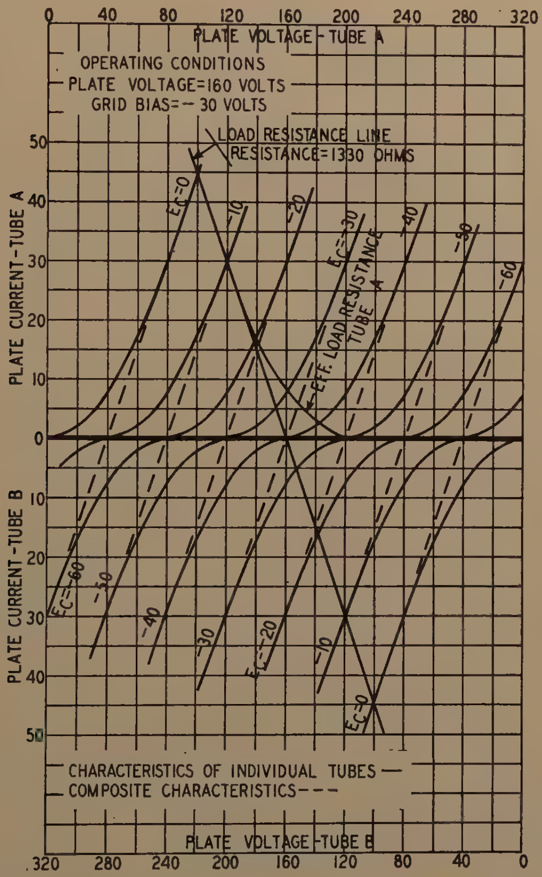


Fig. 2—Method for obtaining composite characteristics.

plotted as a function of plate voltage for different values of grid voltage on tubes *A* and *B*. The curves on tube *B* are inverted with the zero plate voltage at the right-hand end of the abscissa and the currents plotted as negative ordinates; the normal operating plate voltages of the two tubes are at the same point. The so-called composite characteristics (shown by broken lines) are constructed by adding algebraically the plate-current ordinates of the two plots for corresponding

grid voltages. Thus, the curves on both tubes for normal grid bias are added directly. The curve on tube A for a given increment of voltage less than normal bias is added to the curve on tube B for the same increment more than normal bias.

It will be seen in Fig. 2 that the composite characteristics are approximately straight lines, and that the effective current at normal plate and grid voltages is zero. This is true in the case where the two tubes are similar. When the two are not similar the curves may not be straight, and there will be some value of effective current at normal voltages.

The load resistance is drawn through the operating point on the composite curves, and the power output and distortion determined in the usual way. The value of resistance used is that connected across a secondary having the same number of turns as one half of the primary winding. The effective plate-to-plate load resistance is four times this value.

Since the composite characteristics are approximately straight lines, there is little distortion and the optimum load resistance is approximately equal to the composite tube resistance (one half the plate resistance of a single tube at the operating point).

In Fig. 2 is shown also the effective load resistance of tube A, obtained from the voltage relations of the composite curves. It will be seen that this load resistance is far from constant. In fact, at the optimum conditions, *each tube operates into an effective load resistance equal to its own internal resistance at every point throughout the cycle.* It is this that permits the high efficiency and low distortion of a push-pull amplifier.

When the two tubes are not similar, there is a net rectification in the effective current. This should be taken into account by a correction in the operating conditions on the composite diagram, in the same manner as described by Kilgour[4] for single-tube amplifiers where there is rectification.

Such abnormal conditions as different numbers of turns on the two sections of the primary of the output transformer, or on the grid transformer; phase difference between the two grid voltages; or couplings less than unity between the two sections of the primary of the output transformer, may be analyzed by this method, if proper account is taken of these factors in plotting the individual characteristics, and constructing therefrom the composite characteristics. For example, to take care of the case of different numbers of turns on the two output windings, the plate voltage scale on the tube having the smaller num-

[4] C. E. Kilgour, Proc. I. R. E., vol. 19, no. 1, p. 42; January, (1931).

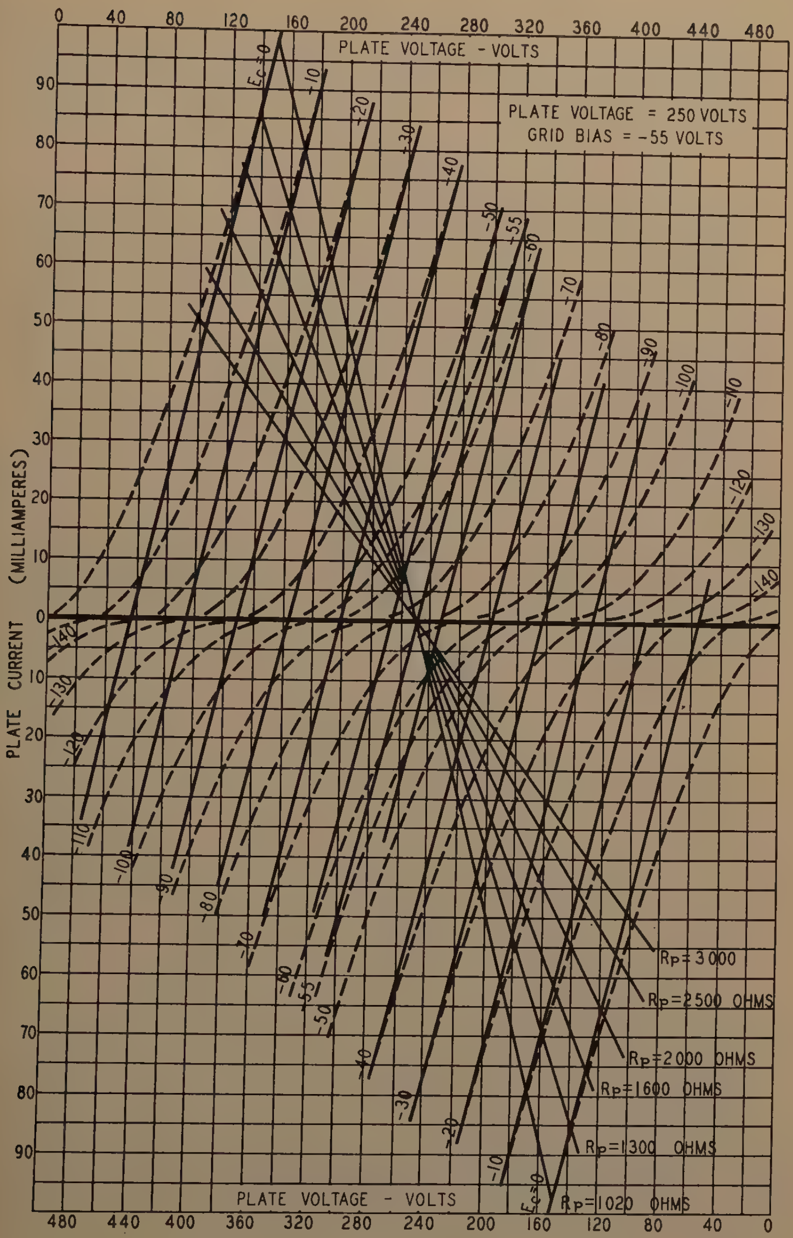


Fig. 3—Composite characteristics for two average 45 type tubes at 55 volts bias. Individual tube characteristics shown by broken lines.

ber of turns should be expanded, while the plate current scale should be contracted, both in proportion to the ratio of turns.

Of course, a set of composite characteristics must be constructed for each operating plate voltage and grid bias which it is desired to study.

Experimental Verification

In view of the very considerable difference between the results as indicated by this method and those as indicated by the previous meth-

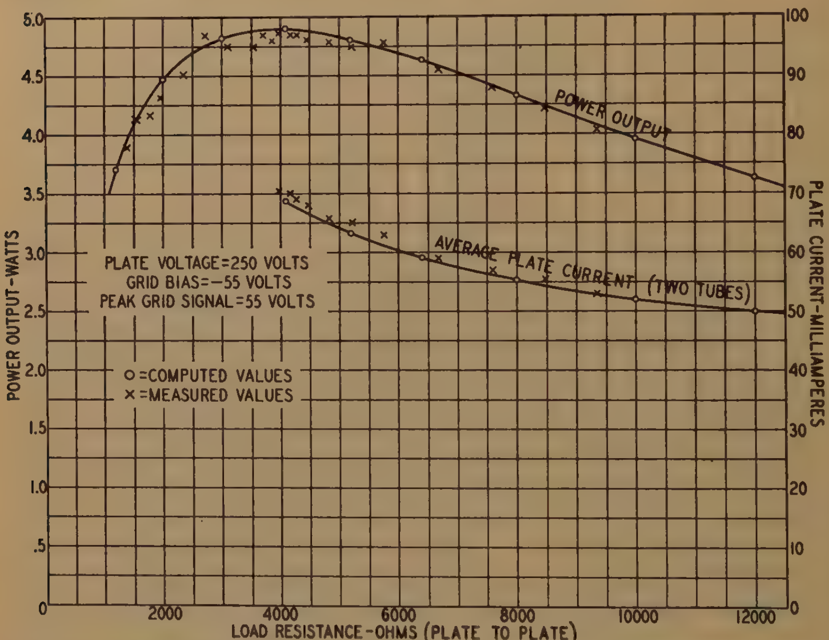
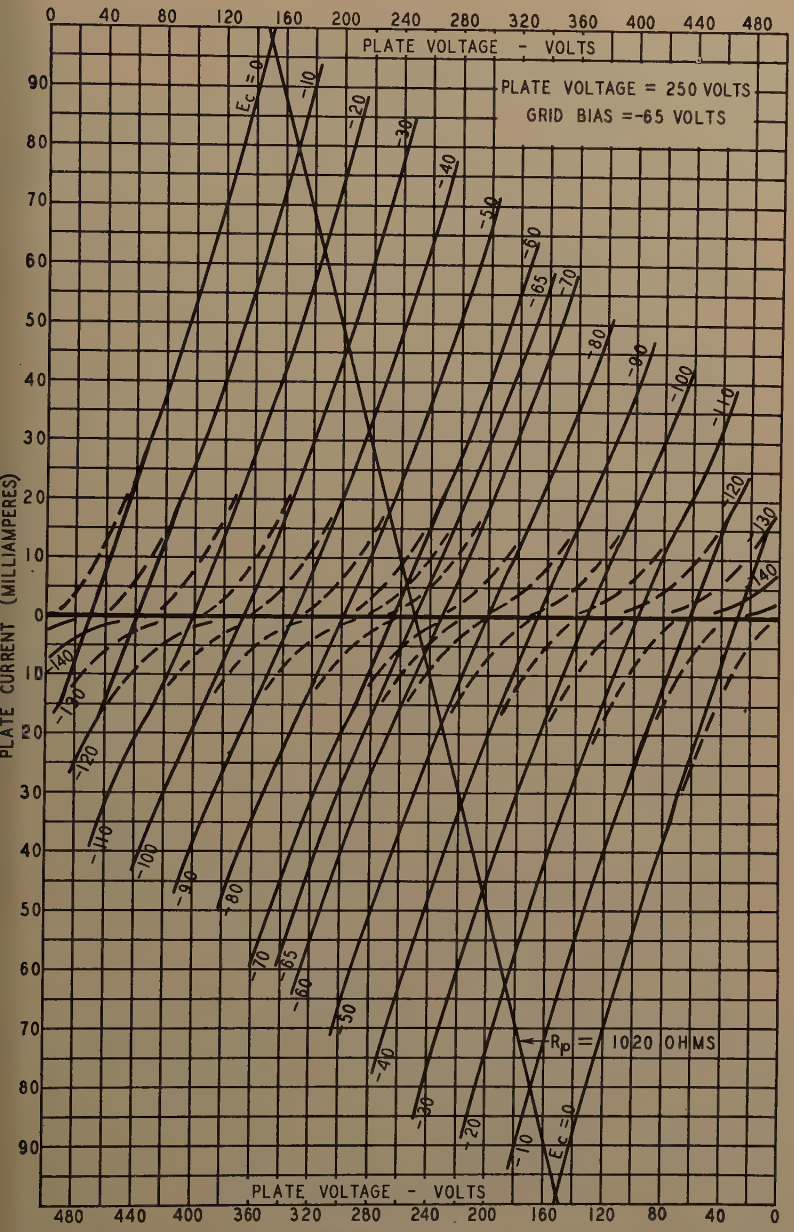


Fig. 4—Comparison between values of power output and average plate current as computed from Fig. 3 and measured values.

ods, it was felt desirable to make a thorough check by measurements on a push-pull stage under a variety of conditions.

The measurements were made in a test set wherein a sine wave voltage is applied to the two grids through a mid-tapped transformer. The output is obtained across a mid-tapped choke connected between the two plates, with the plate supply brought to the mid-tap. This choke has low resistance and high coupling between the two windings. The voltage developed across the load resistance is determined by balancing it against a measured sine wave voltage. The residual voltage after this balance is distortion introduced in the push-pull stage.



. 5—Composite characteristics for two average 45 type tubes at 65 volts bias. Load resistance 1020 ohms (4080 ohms plate-to-plate).

The power output is computed from the known values of resistanc and voltage.

Fig. 3 shows the composite characteristics for two average 45 typ tubes at 250 volts plate voltage and 55 volts grid bias. Varying loa resistance lines were drawn through this operating point, and th power output calculated. For example: with a resistance of 1020 ohms and a peak grid signal of 55 volts, the peak plate current is 98.0 milli amperes, while the peak voltage is 100.0 volts. The power, W_o, i $(98\times100/2)=4.90$ watts, neglecting distortion. (A check on the dis

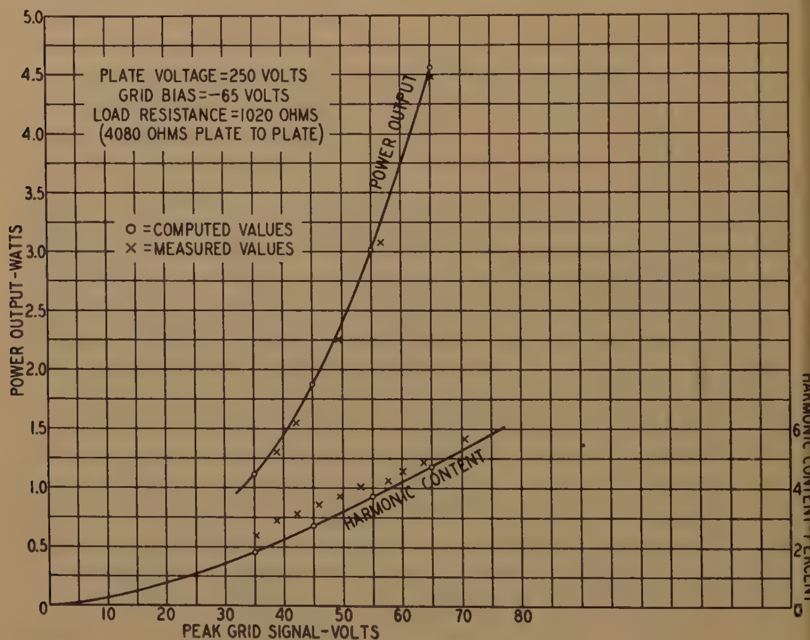


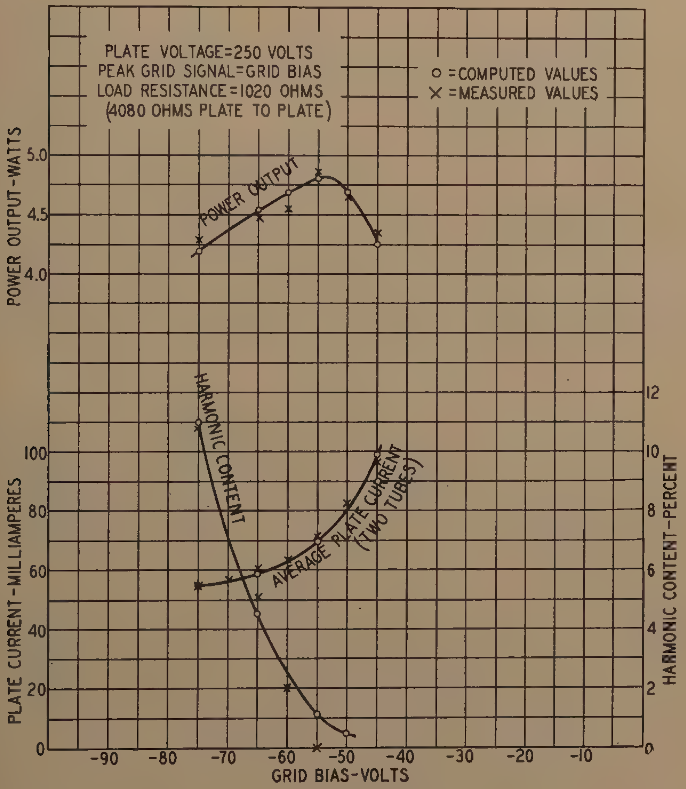
Fig. 6—Comparison between values of power output and harmonic content a computed from Fig. 5 and measured values.

tortion by the 24-ordinate method shows a power of 4.80 watts.) Th average plate current per tube was calculated for the cases where th current in an individual tube does not reach zero by the simple fo mula

$$I_b = I_{bo} + \frac{I_{max} + I_{min} - 2I_{bo}}{4}$$

where I_b is the average current with signal, I_{bo} the plate current with out signal, and I_{max} and I_{min} the maximum and minimum values t which the current swings with signal, all values being determined fro the load line for an individual tube.

Fig. 4 shows a plot of these computed values for various load re-
stances, with the measured values on two tubes selected to be as
early average as possible indicated for comparison. The maximum
rror in average plate current is about 3 per cent, while the average er-
or is considerably better than this. The maximum error in power
utput is also about 3 per cent, while the average error is around one



g. 7—Comparison between computed and measured values of power output, average plate current, and harmonic content for two average 45 type tubes at various grid biases.

lf of this. In view of the fact that the distortion is neglected in com-
ıting these values of power output and that the corrected values
ould be even nearer the measured values, this is an entirely satisfac-
ry check.

Fig. 5 shows the composite curves on the 45 type tubes at 65 volts
id bias and 250 volts plate potential. From these were determined the
wer output and distortion as functions of grid signal at 1020 ohms

load resistance (4080 ohms plate-to-plate), using the 24-ordinat method—which becomes only a 6-ordinate method for such symmet rical waves. The computed values are plotted in Fig. 6 with the meas ured values indicated for comparison. It will be seen that the check i very good for power output. The distortion agrees well at the highe values. At the lower values the agreement is not so good, due no doub to the difficulty in measuring low values of distortion, and perhaps t some second harmonic due to unbalance in the tubes used for the check This check of power output is of special significance, as it is under con ditions between class A and class B.

Fig. 7 shows power output, per cent harmonic, and average plat current plotted as functions of grid bias for a load resistance of 102 ohms, with the peak grid signal equal to the grid bias. The composit curves from which the 45-volt, 50-volt, 60-volt, and 75-volt point were obtained are not shown, as the method should be clear from th foregoing. It will be seen that the agreement between computed an measured values for all three quantities again is very good. This cove a range of operating conditions from extreme class A to extreme clas B.

Conclusion

It is to be concluded from the foregoing that the method here pre sented is accurate. It is simple, rigorous, and straightforward, and i equally applicable to class A, class B, or intermediate operating cond tions.

Acknowledgment

The writer wishes to express his gratitude to Mr. W. R. Ferris c this laboratory for his great assistance in making the experiment verification, and in preparing the data here presented.

Proceedings of the Institute of Radio Engineers
olume 21, Number 4 *April, 1933*

THEORY OF THE DETECTION OF TWO MODULATED WAVES BY A LINEAR RECTIFIER*

BY
CHARLES B. AIKEN
(Bell Telephone Laboratories, Inc., New York City)

Summary—*In this paper there is developed a mathematical analysis of the etection, by a linear rectifier, or two modulated waves. Solutions are obtained which e manageable over wide ranges of values of carrier ratio and degrees of modulation. hese solutions are of greater applicability and are more convenient than those pre- ously obtained, and give a full treatment of the action of an ideal linear rectifier nder the action of two modulated waves.*

The development is first made in terms of the derivatives of zonal harmonics an angle which is directly related to the phase difference between the carriers. As ese derivatives are tabulated functions the solution is convenient.

The solutions are limited by the condition that $K<(1-M)/(1+m)$, K being the rrier ratio, M the degree of modulation of the stronger carrier, and m that of the eaker. Two methods of attack are developed one of which is applicable when K is nall and M and m large, and the other when M and m are small and K large.

The cases of identical and of different programs are both considered and a umber of curves are given showing the magnitudes of various output frequency com- onents under typical operating conditions.

In the latter part of the paper the phase angle between the carriers is set equal μt so that a beat note exists. There is then considered the effect of a noise back- ound on the reception of signals on shared channels, and it is shown that much ss "flutter" effect and much less distortion of the desired signal will result from the e of a linear rectifier than from the use of a square-law rectifier under the same nditions.

Finally, brief consideration is given to heterodyne detection and to "masking" fects.

INTRODUCTION

THE rise of shared channel broadcasting of both the nonisochronous and supposedly isochronous types has raised to a level of some importance the phenomena which result from the simul- neous reception of two modulated waves. The wide use of detectors hich are approximately linear, and their capacity for high quality production of a single wave of the usual form, make the study of the ctification of two waves by such devices a matter of particular inter- t.

In an earlier[3] paper an analysis has been made of the detection of ared channel signals by both parabolic and linear rectifiers, but it

* Decimal classification: R134. Original manuscript received by the Insti- te, October 31, 1932.
[3] Figures refer to bibliography.

was necessary to limit the carrier ratio to about 0.1 for the latter typ of detector, because of the rather slow convergence of the series solu tions which were obtained. This range is sufficient to cover the cas of signals having carriers which differ by several cycles or more sinc higher ratios give rise to intolerable interference. But when the carrie beat is reduced to a small fraction of a cycle per second, larger values o carrier ratio are entirely permissible from a practical standpoint an it becomes necessary to extend the range of the analysis to include suc values.

In the present paper there is developed a method of analysis whic is valid and manageable for all values of carrier ratio and percentag modulation which are such that the envelope of one wave is alway greater than that of the other. Although this restriction prohibits th examination of a completely modulated wave from the stronger sta tion, nevertheless the investigation covers a wide range of practica applications. For example, the case where the two stations are eac modulated 30 per cent and the carrier ratio is 0.5, comes within th limitations of the theory. Another case which is included is that i which the weaker station is modulated 100 per cent and the stronge station is unmodulated, the carrier ratio again being 0.5.

In the development of the analysis advantage is taken of the fac that the carriers may be considered as differing in phase by a fixe angle $(\pi-\theta)$, and the expansion is in terms of zonal harmonics of θ In addition to the treatment of the isochronous case an extension o the analysis is made which covers the nonisochronous case, thus givin a complete treatment of the linear detection of two waves.

A number of curves have been computed for various numerica values of the carrier ratio, degrees of modulation, etc.; but an exten sive exposition of the results obtained by the application of this analy sis to the problems of isochronous common-frequency broadcastin will be reserved for a later paper. At that time there will be considere the more practical aspects of the distortions resulting from both para bolic and linear rectifiers when the carrier ratio is large. The presen paper will serve as a basis for this later work.

It is assumed that the load impedance associated with the rectifie is either negligible or a pure resistance at all frequencies. This is a goo approximation under most conditions, since, in conventional forms c circuits intended for the linear rectification of high frequencies, th load is usually negligible for those frequencies which are passed b the selective networks ahead of the detector, and is essentially a pu resistance for the low frequencies resulting from the process of rectifica tion. If the load does not fulfill these conditions the results will,

ourse, be modified.[10] However, the effects of the variation of load npedance with frequency are outside the scope of the chief problems ere considered, and such cases are specifically excluded from this nalysis, as well as from that of the two earlier papers in this field.[3,5]

Set-Up of Problem

Let us first review the action of a linear rectifier. If such a device as impressed upon it a voltage wave $v = V \cos \omega t$ then one half of the ave is suppressed and the rectified voltage acting in the output circuit expressed by the Fourier series:

$$v_{\text{out}} = \frac{V}{\pi}\left[1 + \frac{\pi}{2}\cos \omega t + \frac{2}{1.3}\cos 2\omega t - \frac{2}{3.5}\cos 4\omega t \cdots\right]. \tag{1}$$

If, instead of having a constant amplitude, the impressed wave is odulated so that $V = E(1 + M \cos Pt)$, then the corresponding output obtained from (1) by substituting this new value for V. Thus

$$v_{\text{out}} = \frac{E}{\pi}(1 + M \cos Pt)\left[1 + \frac{\pi}{2}\cos \omega t + \cdots\right]. \tag{2}$$

If $P/2\pi$ is an audio frequency and $\omega/2\pi$ a radio frequency then e only audio term present in (2) will be $ME/\pi \cos Pt$ and the detecon is distortionless. The products of $\cos Pt$ with the terms in $n\omega t$ give dio frequencies.

Now, instead of a single wave let us impress upon the rectifier two aves which are

$$E[1 + M \cos Pt] \cos \omega t$$

nd,

$$e[1 + m \cos (pt + \beta)] \cos (\omega t + \gamma). \tag{3}$$

he input wave will be the sum of these two and will be a perfectly eneral expression for the signals received from two stations since such uantities as relative phase of departure from the transmitters, differce in length of path of propagation, etc., can readily be taken into ccount by assigning proper values to β and γ. This is discussed in Apendix A.

The next step is to express the two waves as a single wave.

Let,

$$\left.\begin{aligned} A &= E[1 + M \cos Pt] \\ B &= e[1 + m \cos (pt + \beta)] \end{aligned}\right\}. \tag{4}$$

V now represents the amplitude of the equivalent wave then it is

evident from Fig. 1 that

$$V = \sqrt{(A - B\cos\theta)^2 + B^2\sin^2\theta} = \sqrt{A^2 + B^2 - 2AB\cos\theta} \tag{5}$$

and that,

$$\cos\delta = \frac{A - B\cos\theta}{V} \qquad \sin\delta = \frac{B\sin\theta}{V} \tag{6}$$

θ being the supplement of γ. The phase angle between the carriers is γ but θ will be more useful in developing the expansion.

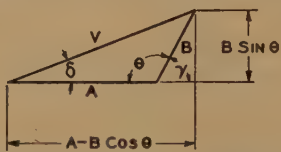


Fig. 1—Two waves of amplitudes A and B, respectively, and differing in phase by an angle γ, may be combined into a single wave of amplitude V and of phase angle δ, as here indicated.

The impressed signal may now be written:

$$v = \sqrt{A^2 + B^2 - 2AB\cos\theta}\,\cos\left[\omega t + \delta(\theta, t)\right] \tag{7}$$

in which δ is a function of θ and of time.

In the earlier paper already mentioned it has been stated that δ could be neglected without affecting the calculation of the rectified current. This has been questioned by several readers and consequently it has seemed desirable to discuss this matter in detail. Hence a proof of the validity of neglecting the phase angle is given in Appendix B. As a result of this proof it may be briefly stated that $\cos\left[\omega t + \delta(\theta, t)\right]$ is a phase modulated wave, and that the side bands due to this modulation contribute nothing to the constant term of the Fourier expansion indicated in (1). Hence a frequency analysis of V will give a complete description of the output of all radian velocities which do not contain ω. As far as such frequencies are concerned δ may be neglected in (7) and the rectified voltages will be given by

$$V_{out} = \frac{V}{\pi} = \frac{1}{\pi}\sqrt{A^2 + B^2 - 2AB\cos\theta}. \tag{8}$$

The problem is then that of the frequency analysis of (8).

Before undertaking this it should be emphasized that δ cannot be neglected when it is desired to deal with radian velocities containing ω. A computation of the side bands of ω from V alone leads to incorrect results. Hence it is misleading to say, as has been done from time t

time, that two unmodulated waves of different frequencies are equivalent to a single carrier wave which is modulated to an extent which is determined by the coefficients of the Fourier expansion of the amplitude V. A comparison of the results obtained when two such waves are rectified by parabolic and by linear detectors with the results of rectification of an ordinary modulated wave by these two types of detectors shows that the degree of modulation which is assigned to the two heterodyning waves must be a function of the type of detector employed.

Expansion of V

Proceeding now to the frequency analysis of V let

$$r = \frac{B}{A} \tag{9}$$

then,

$$V = A\sqrt{1 - 2r\cos\theta + r^2}. \tag{10}$$

Let,

$$R = \sqrt{1 - 2r\cos\theta + r^2} \tag{11}$$

$$V = AR^2\left(\frac{1}{R}\right).$$

A convenient expression for $1/R$ is†

$$\frac{1}{R} = P_0(\cos\theta) + rP_1(\cos\theta) + r^2P_2(\cos\theta) + \cdots$$

$$\cdots + r^qP_q(\cos\theta) + \cdots \tag{13}$$

provided $r < 1$.

$P_n(\cos\theta)$ is a function of $\cos\theta$ only and is commonly designated as a zonal harmonic, or Legendre's polynomial of order n. The zonal harmonic P_n must here be distinguished from the radian velocity P of (1).

From (10) and (13) we have

$$V = A(1 - 2r\cos\theta + r^2)(P_0 + rP_1 + r^2P_2 + \cdots) \tag{14}$$

$$V = A[P_0 + (P_1 - 2P_0\cos\theta)r + (P_0 - 2P_1\cos\theta + P_2)r^2 + \cdots$$

$$+ \cdots (P_{q-2} - 2P_{q-1}\cos\theta + P_q)r^q + \cdots]. \tag{15}$$

Now a relation between the P's is

$$(q+1)P_{q+1} - \cos\theta(2q+1)P_q + qP_{q-1} = 0 \tag{16}$$

† *See* Pierpont, "Functions of a Complex Variable," art. 223, p. 497.

by (1), page 505, of Pierpont. This may be written

$$P_{q+1} - 2P_q \cos\theta + P_{q-1} = \frac{P_q \cos\theta - P_{q+1}}{q}. \tag{17}$$

We also have

$$P_0(\cos\theta) = 1 \qquad P_1(\cos\theta) = \cos\theta. \tag{18}$$

From (15), (17), and (18) it follows that

$$V = A\left[1 - r\cos\theta + (P_1\cos\theta - P_2)\frac{r^2}{1} + (P_2\cos\theta - P_3)\frac{r^3}{2} + \cdots \right.$$
$$\left. \cdots + (P_{q-1}\cos\theta - P_q)\frac{r^q}{q-1} \cdots \right]. \tag{19}$$

From (3), page 505, of Pierpont it follows that

$$P_{q-1}\cos\theta - P_q = \frac{1-\cos^2\theta}{q}\,\frac{dP_{q-1}}{d(\cos\theta)} = -\frac{\sin\theta}{q}\,\frac{dP_{q-1}}{d\theta} \tag{20}$$

whence,

$$V = A\left[1 - r\cos\theta - r\sin\theta\left(\frac{r}{1.2}\,\frac{dP_1}{d\theta} + \frac{r^2}{2.3}\,\frac{dP_2}{d\theta} + \cdots \right.\right.$$
$$\left.\left. \cdots + \frac{r^q}{q(q+1)}\,\frac{dP_q}{d\theta} + \cdots\right)\right] \tag{21}$$

or,

$$V = A - B\cos\theta - B\sin\theta\left(\frac{r}{1.2}P_1' + \frac{r^2}{2.3}P_2' \cdots \right.$$
$$\left. \cdots + \frac{r^q}{q(q+1)}P_q' + \cdots\right). \tag{22}$$

There have been developed two methods of extracting the various audio frequencies from (22). One of these gives series which do not converge very rapidly when e/E is greater than about 0.5 but which are satisfactory for smaller values of this ratio. This method allows larger values of m and M than does the second method.

The second method of attack yields expressions which are applicable when the carrier ratio is larger. The results are obtained by neglecting all powers of M and m higher than the third and summing the remaining series in θ and K, the carrier ratio. With modulations of 30 per cent or less the error introduced is quite small. The two methods together cover all ranges of K, M, and m which are possible without the smaller wave suddenly becoming the larger at some point in the modulating cycle.

Before proceeding to the discussion of the solutions it will be well to point out the condition which must be fulfilled by M, m, and the carrier ratio in order that the expressions already developed may be valid.

In order that (13) may be true it is necessary that $r<1$ or,

$$r = \frac{K(1 + m\cos pt)}{(1 + M\cos Pt)} < 1$$

in which,

$$K = e/E.$$

r will have its maximum value when $\cos pt = +1$ and $\cos Pt = -1$. Hence we must have,

$$\frac{K(1+m)}{(1-M)} < 1 \qquad (23)$$

in order that (13), and hence (22) and all other expressions based upon (13), may be true.

Equation (23) amounts to restricting the relative amplitudes in such a way that there is no sudden change in the law describing the shape of the envelope or, as has been stated above, it amounts to requiring that what is normally the smaller wave shall not become the larger when the amplitude of the larger is near its minimum and that of the smaller near its maximum. This restriction is not very serious from a practical standpoint.

First Method

It is now necessary to extract the various component frequencies from (22). (r) contains ($\cos Pt$) in the denominator and hence further expansions are necessary. $1/(1+M\cos Pt)q$ can be expanded by the binomial theorem and the terms in $\cos^n pt$ reduced to terms in multiples of Pt. However, it is more convenient to expand the fraction into a Fourier series, since power series expansion yields an infinite series for each a_{qn}.

$$\frac{1}{(1+M\cos Pt)^q} = \frac{a_{q0}}{2} + a_{q1}\cos Pt + a_{q2}\cos 2Pt + \cdots$$
$$\cdots + a_{qn}\cos nPt + \cdots. \qquad (24)$$

The sine terms in the expansion all vanish. The cosine coefficients may be evaluated by reference to D. B. de Haan's, "Nouvelles Tables

D'Intégrales Défines", Table 66, No. 5, which in the present notation gives:

$$a_{qn} = \frac{(-1)^n}{2^{q-2}} \cdot M^n \alpha^{n+q}(\alpha+1)^{q-n-1} C_n{}^{q+n-1} \sum_{r=0}^{q-1} \frac{C_r{}^{q-1} C_r{}^{q-n+1}}{C_r{}^{n+r}} \left(\frac{\alpha-1}{\alpha+1}\right).$$

In which C_a^b is the binomial coefficient

$$C_a^b = \frac{b(b-1)\cdots(b-a+1)}{a!}.$$

α is given below.

a_{1n} may be evaluated with less labor by the use of Formula 12, Table 64, of the above-mentioned author.

A number of the coefficients are as follows:

TABLE I

Values of a_{qn}.

qn	0	1	2	3
1	2α	$-2\alpha\mu$	$2\alpha\mu^2$	$-2\alpha\mu^3$
2	$2\alpha^3$	$-2M\alpha^3$	$2\alpha^3 + \frac{4}{M^2}(1-\alpha)$ $= 2\alpha^3 - \frac{4}{M}\alpha\mu$	$-2M\alpha^3 + \frac{8\alpha\mu^2}{M}$
3	$(2+M^2)\alpha^5$	$-3M\alpha^5$	$3M^2\alpha^5$	$-3M\alpha^5 + \frac{4\alpha^3}{M} - \frac{8\alpha\mu}{M^2}$
4	$(2+3M^2)\alpha^7$	$-M(4+M^2)\alpha^7$	$(2+3M^2)\alpha^7 - 2\alpha^5$ $= 5M^2\alpha^7$	$-5M^3\alpha^7$
5	$2\left(1+3M^2+\frac{3M^4}{8}\right)\alpha^9$	$-5M\left(1+\frac{3M^2}{4}\right)\alpha^9$	$\frac{5}{2}M^2\left(3+\frac{M^2}{2}\right)\alpha^9$	$-\frac{35}{4}M^3\alpha^9$

$$\alpha = \frac{1}{\sqrt{1-M^2}} \qquad \mu = \frac{M}{1+\sqrt{1-M^2}} = \frac{M\alpha}{1+\alpha}$$

It will now be necessary to distinguish two cases, one in which the modulations of the two stations are of different radian velocities, and a second case in which the modulating velocities are identical except for an arbitrary phase angle.

Case of Different Modulating Frequencies

In this case the phase angle β is of no significance and may be neglected since it does not affect the amplitudes of any of the frequency components, and their abolute phases are of no interest. Hence set $\beta=0$ in (4) and substitute (9), (4), and (24) into (22). There results:

$$\left.\begin{aligned} V = {} & E(1 + M \cos Pt) - e \cos \theta\,(1 + m \cos pt) \\ & - e \sin \theta \Bigg(F_1(1 + m \cos pt)^2 \left[\frac{a_{10}}{2} + \sum_{n=1}^{\infty} a_{1n} \cos n\,Pt\right] \\ & \qquad + F_2(1 + m \cos pt)^3 \left[\frac{a_{20}}{2} + \sum_{n=1}^{\infty} a_{2n} \cos n\,Pt\right] \\ & \qquad + \cdots \\ & \qquad + F_q(1 + m \cos pt)^{q+1} \left[\frac{a_{q0}}{2} + \sum_{n=1}^{\infty} a_{qn} \cos n\,Pt\right] \\ & \qquad\quad + \cdots\cdots\cdots\cdots\cdots\cdots \Bigg) \end{aligned}\right\} \quad (25)$$

n which,

$$F_q = \frac{K^q P_q'}{q(q+1)} \qquad\qquad K = \frac{e}{E}\,.$$

From this there may readily be extracted the expressions for the arious frequencies. Thus the amplitude of the angular velocity P is:

$$\begin{aligned} E_p = {} & \frac{EM}{\pi} - \frac{e \sin \theta}{\pi} \Bigg[a_{11}F_1\left(1 + \frac{m^2}{2}\right) + a_{21}F_2\left(1 + \frac{3m^2}{2}\right) \\ & + a_{31}F_3\left(1 + 3m^2 + \frac{3m^4}{8}\right) + \cdots \\ & \cdots + a_{q1}F_q\frac{G_{q+1,0}}{2} + \cdots \Bigg] \end{aligned} \qquad (26)$$

n which $G_{q0}/2$ is the constant term contained in $(1+m \cos x)^q$. In ubsequent expressions it will be necessary to employ the quantity $_{qn}$, which is the coefficient of cos nx in the Fourier expansion of $1+\cos x)^q$. The evaluation of these constants is a simple matter and ill not be discussed here. Values of the lower orders of G_{qn} are given Table II.

The factor $1/\pi$ in (26) results from the expansion (1), and each omponent of output voltage must contain it.

At this point it may be noted that the extraction of terms from (25) make up the series (26) must be justified by establishing the conver-ence of the extracted series. This has been done by Mr. L. A. MacColl Bell Telephone Laboratories and shows that when (23) is fulfilled, en the extraction of terms to form the expressions for the component equencies is valid, and leads to the correct results.

TABLE II
Values of G_{qn}

$q \backslash n$	0	1	2	3	4	5
1	2	m	0	0	0	0
2	$2+m^2$	$2m$	$\frac{m^2}{2}$	0	0	0
3	$2+3m^2$	$3m\left(1+\frac{m^2}{4}\right)$	$\frac{3m^2}{2}$	$\frac{m^3}{4}$	0	0
4	$2+6m^2+\frac{3m^4}{4}$	$4m\left(1+\frac{3m^2}{4}\right)$	$m^2\left(3+\frac{m^2}{2}\right)$	m^3	$\frac{m^4}{8}$	0
5	$2+10m^2+\frac{15m^4}{4}$	$5m\left(1+\frac{3m^2}{2}+\frac{m^4}{8}\right)$	$5m^2\left(1+\frac{m^2}{2}\right)$	$\frac{5}{2}m^3\left(1+\frac{m^2}{8}\right)$	$\frac{5m^4}{8}$	$\frac{m^5}{16}$
6	$2+15m^2+\frac{45}{4}m^4+\frac{5}{8}m^6$	$6m\left(1+\frac{5}{2}m^2+\frac{5}{8}m^4\right)$	$\frac{15}{2}m^2\left(1+m^2+\frac{m^4}{16}\right)$	$5m^3\left(1+\frac{3}{8}m^2\right)$	$\frac{3}{8}m^4\left(5+\frac{m^2}{2}\right)$	$\frac{3}{8}$

The amplitude of cos pt may be readily extracted from (25) and i

$$E_p = \frac{-e}{\pi}\left[m\cos\theta + \sin\theta\sum_{q=1}^{\infty} F_q \frac{a_{10}}{2} G_{q+1,1}\right]. \qquad (32$$

The amplitude of the second harmonic of the stronger sign al is

$$E_{2P} = -\frac{e}{\pi}\sin\theta\sum_{q=1}^{\infty} F_q a_{q2}\frac{G_{q+1,0}}{2}. \qquad (33$$

The second harmonic of the weak signal is

$$E_{2p} = \frac{-e}{\pi}\sin\theta\sum_{q=1}^{\infty} F_q \frac{a_{q0}}{2} G_{q+1,2}. \qquad (34$$

The direct-current term is

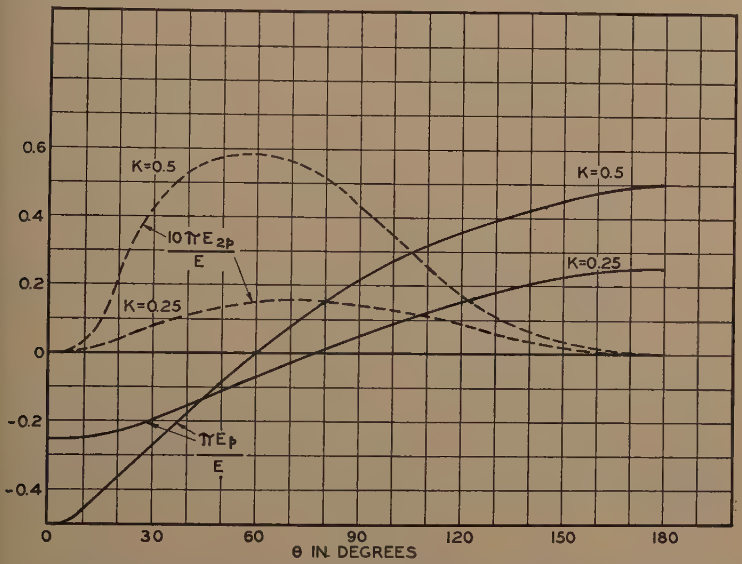
$$E_{D.C.} = \frac{E}{\pi}\left[1 - K\cos\theta - K\sin\theta\sum_{q=1}^{\infty} F_q \frac{a_{q,0}}{2}\,\frac{G_{q+1,0}}{2}\right]. \qquad (35$$

The above series converge rapidly for small values of K. For value of K near unity, m and M are necessarily small, and the secon method, which is discussed below, is more suitable. In making numer cal computations the values of $P_q' = dP_q/d\theta$, which is contained in F may be taken from tables of this quantity which are to be found c pages 88–89 of Jahnke und Emde, "Funktionentafeln."

In Fig. 2 are shown plots of the quantities $\pi E_p/E$ and $10\pi E_{2p}/$ for the case in which the stronger signal is unmodulated and the weak signal is modulated 100 per cent. The calculation of the curves i cluded terms up to P_5'. This gives very satisfactory accuracy exce

or the second harmonic when $K=0.5$. In this curve, for $\theta=90$ degrees, erms including P_7' were used and the accuracy is fair near the maxi-ıum but is poor for the smaller values. However the absolute error not large at any point. It is interesting to note that over a consider-ble portion of the range of θ the second harmonic is greater than 10 er cent of the fundamental.

These curves are symmetrical about the ordinates through $\theta=0$ nd through $\theta=180$ degrees. This type of symmetry holds for all the ırves in this paper which have either θ or β as abscissa.



g. 2—Fundamental and second harmonic of the audio-frequency ouput of a linear rectifier upon which is impressed an unmodulated carrier together with a smaller isochronous carrier which is modulated 100 per cent by a radian velocity p. K is the ratio of the carrier amplitudes and θ is 180 degrees minus the phase angle between the carriers. E is the amplitude of the large carrier and E_p the amplitude of the output voltage of frequency $p/2\pi$.

In Fig. 3 are shown similar curves except that the weaker station modulated only 30 per cent. In this figure the curves for $K=0.5$ ere calculated by the second method, which is to be developed below.

The curves of Figs. 2 and 3 indicate the variations in intensity and ıality which may be expected during soft portions of the desired pro-am when another station transmitting a different program is ad-sted to exactly the same carrier frequency. These curves also show the ect of mixing a local carrier E, with a received signal, $e(1+m\cos pt)$.

In Fig. 4 are shown the direct-current and fundamental frequency

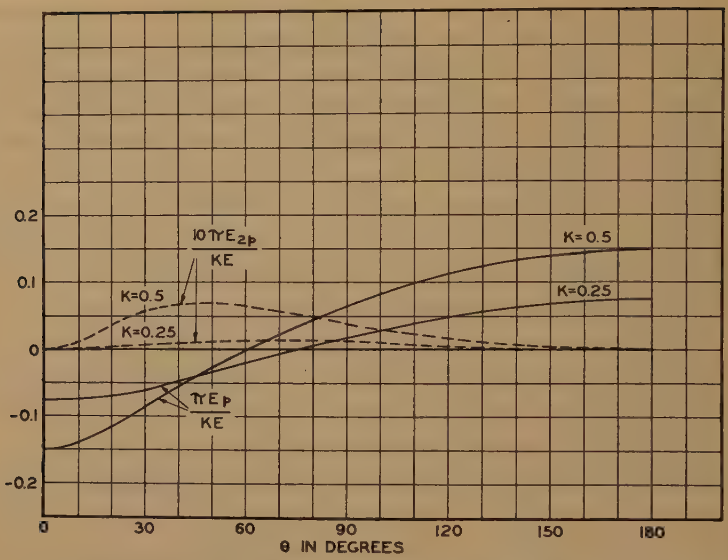


Fig. 3—Conditions are the same as in Fig. 2, except that the weaker carrier modulated 30 per cent.

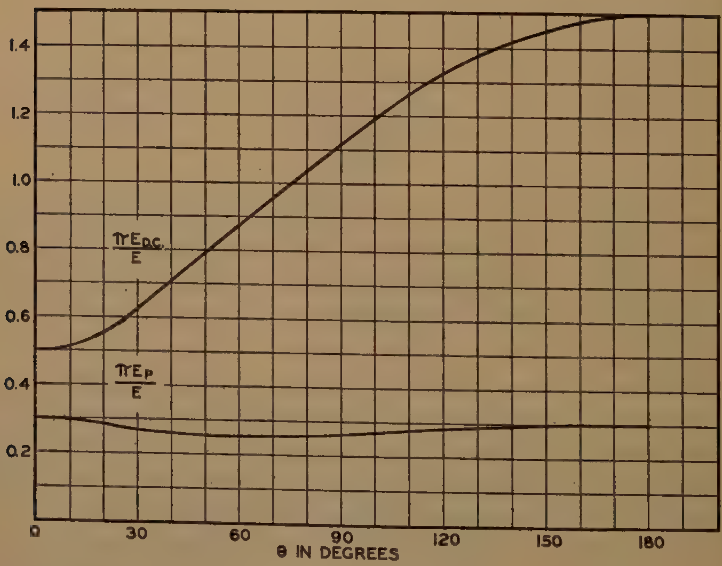


Fig. 4—Direct-current and fundamental audio-frequency outputs when t strong carrier is modulated 30 per cent and the weaker carrier is unmod lated. The carrier ratio is 0.5.

outputs when the strong wave is modulated 30 per cent and the interfering carrier is unmodulated and is half as strong as the desired. The variation in the amplitude of cos Pt is not large but the variation in the direct-current component is very large. If the rectified direct-current were used to actuate an automatic gain control system then large variations in the audio output of the receiving set would result from a slow variation in the phase angle between the carriers. Points on the curves of Fig. 4 have been computed by both the first and second methods.

When both stations are modulated practical interest attaches chiefly to the case in which the programs are identical. This case may be treated by either of the two methods here used but since the modulations are limited by (23) the interesting case of equal modulations will have m and M well under 0.5, and hence this case is conveniently treated by the second method.

Second Methods‡

Note that

$$r^q = \frac{K^q[1 + m\cos(pt+\beta)]^q}{[1 + M\cos Pt]^q}. \tag{36}$$

Expand both numerator and denominator of the fraction by the binomial theorem and multiply the resulting series together. Discard all terms which contain a factor of the form m^aM^b in which $a+b$ is greater than three. From the result it is possible to write,

$$\begin{aligned}
\sum_{q=1}^{\infty}\frac{r^qP_q'}{q(q+1)} &= \sum_{q=1}^{\infty}\frac{K^qP_q'}{(qq+1)} + [m\cos(pt+\beta) - M\cos Pt]\sum\frac{K^qP_q'}{q+1}\\
&+ \frac{m^2}{2}\cos^2(pt+\beta)\sum\frac{(q-1)}{q+1}K^qP_q'\\
&+ \frac{m^3}{6}\cos^3(pt+\beta)\sum\frac{(q-1)(q-2)}{q+1}K^qP_q'\\
&- mM\cos(pt+\beta)\cos Pt\sum\frac{q}{q+1}K^qP_q'\\
&- \frac{m^2M}{2}\cos^2(pt+\beta)\cos Pt\sum\frac{q(q-1)}{q+1}K^qP_q'\\
&+ \frac{M^2}{2}\cos^2 Pt\sum K^qP_q' + \frac{mM^2}{2}\cos(pt+\beta)\cos^2 Pt\sum qK^qP_q'\\
&- \frac{M^3}{6}\cos^3 Pt\sum(q+2)K^qP_q'.
\end{aligned} \tag{37}$$

‡ See footnote, page 614.

This is to be substituted into (22), but before doing this let us note that all of the infinite series, each of which is indicated by Σ in (37), may be expressed in closed form. The methods of obtaining these summations would occupy too much space to be given here. Multiplying (37) through by $K \sin \theta$ and indicating the product of this quantity with a particular series by y with a convenient subscript, it can be shown that:

$$y_1 = K \sin \theta \sum \frac{K^q P_q'}{q+1} = \frac{1 - K \cos \theta}{R_K} - 1 \tag{38}$$

$$y_2 = K \sin \theta \sum q K^q P_q' = \frac{-K^2 \sin^2 \theta}{R_K{}^5}(1 + K \cos \theta - 2K^2) \tag{39}$$

$$y_3 = K \sin \theta \sum K^q P_q' = \frac{-K^2 \sin^2 \theta}{R_K{}^3} \tag{40}$$

$$y_4 = K \sin \theta \sum \frac{q(q-1)}{q+1} K^q P_q' = y_2 - 2y_3 + 2y_1 \tag{41}$$

$$y_5 = K \sin \theta \sum \frac{(q-1)(q-2)}{q+1} K^q P_q' = y_2 - 4y_3 + 6y_1 \tag{42}$$

$$y_6 = K \sin \theta \sum \frac{K^q P_q'}{q(q+1)} = 1 - R_K - K \cos \theta \tag{43}$$

$$y_7 = K \sin \theta \sum \frac{q-1}{q+1} K^q P_q' = y_3 - 2y_1 \tag{44}$$

$$y_8 = K \sin \theta \sum \frac{q}{q+1} K^q P_q' = y_3 - y_1 \tag{45}$$

$$y_9 = K \sin \theta \sum (q+2) K^q P_q' = y_2 + 2y_3. \tag{46}$$

With the foregoing results in hand we are ready to compute any of the frequencies contained in (27). It will be noted that the y's are functions of K and θ and do not contain m or M. Also y_4, y_5, y_7, y_8, and y_9 are expressed in terms of y_1 to y_3. Hence in making computations for a fixed value of K it is well to plot curves of y_1 to y_3 with θ as variable. The frequencies present in (37), and hence in (22), may then be readily computed. Thus the amplitude of the fundamental of Pt is

‡ The method here employed was developed as a sequence to the analysis of the earlier parts of this paper. An alternative method is to let $x = M \cos Pt$, $y = m \cos pt$, and then develop V as a Taylor's series in x and y about the point $x = y = 0$. The desired frequency terms may be extracted from this development. The final results are identical with those obtained by the present analysis.

$$\frac{\pi E_P}{E} = M\left[1 + K\sin\theta\left(\sum\frac{K^q P_q'}{q+1} + \frac{m^2}{4}\sum\frac{q(q-1)}{q+1}K^q P_q' + \frac{M^2}{8}\sum(q+2)K^q P_q'\right) + \frac{m^2}{2}\sum\frac{q}{q+1}K^q P_q'\right] \tag{47}$$

as may be seen by substituting (37) into (22) and extracting the desired terms.

Equation (47) can be written in terms of the y's as follows:

$$\frac{\pi E_P}{E} = M\left[1 + y_1 + \frac{M^2}{8}y_2 + \frac{M^2}{4}y_3 + \frac{m^2}{4}y_2\right] \tag{48}$$

which is readily computed from curves of the y's. A plot of (48) for $K=0.5$, $M=0.3$, and $m=0$ has already been shown in Fig. 4.

The direct-current component is

$$\frac{\pi E_{D.C.}}{E} = R_K - \frac{y_3}{4}(m^2 + M^2) \tag{49}$$

in which,

$$R_K = \sqrt{1 - 2K\cos\theta + K^2}. \tag{50}$$

The right side of (49) differs only slightly from R_K and to a pretty fair order of accuracy we may write

$$\frac{\pi E_{D.C.}}{E} = R_K. \tag{49a}$$

A plot of (49) for $m=0$, $M=0.3$, and $K=0.5$ has been given in Fig. 4.

The second harmonic of Pt is given very simply by

$$\frac{\pi E_{2P}}{E} = -\frac{M^2}{4}y_3 \tag{51}$$

and in the case indicated in Fig. 4 is quite small, having a maximum value of about 2.8 per cent of the fundamental. This maximum occurs in the neighborhood of $\theta = 45$ degrees.

The fundamental of the modulating frequency of the weaker station is:

$$\frac{\pi E_p}{E} = -m\left[1 - R_k + y_1 + \frac{M^2}{4}(y_2 + y_3) + \frac{m^2}{8}(y_2 - y_3)\right]. \tag{52}$$

A plot of this quantity for $K=0.5$, $m=0.3$, and $M=0$ is given in Fig. 3.

The second harmonic of pt is

$$\frac{\pi E_{2p}}{E} = -\frac{m^2}{4} y_3$$

and is also shown in Fig. 3.

Case of Identical Modulating Frequencies

This case is of importance in isochronous broadcasting since the same programs are invariably transmitted. The amplitude of the fundamental audio-frequency output and the amount of harmonic distortion will depend upon the phase angles θ and β as well as upon the degrees of modulation and relative intensities of the two signals.

In writing down the expressions for the various frequency components we set $p=P$ and take due account of the phase angle β. A number of the components which were distinct for the case of $p \neq P$ now coalesce into a single component which differs from other similar components of the same frequency only by a phase angle. When all of the terms, up to and including those of the third order, which yield an angular velocity P are extracted from (22), with the help of (37) and (38) to (46), there results

$$\begin{aligned} M\left[1 + y_1 + \frac{m^2}{4}y_4 + \frac{m^2}{2}(y_3 - y_1) + \frac{M^2}{8}(y_2 + 2y_3)\right] \cos Pt \\ - m\left[1 + y_1 - R_K + \frac{m^2}{8}(y_4 + y_3 - 2y_1)\right. \\ \left. + \frac{M^2}{4}(y_2 + y_3)\right] \cos (Pt + \beta) \\ - \frac{mM^2}{8}(y_2 + y_3) \cos (Pt - \beta) \\ + \frac{m^2 M}{8}(y_4 + 2y_3 - 2y_1) \cos (Pt + 2\beta). \end{aligned} \tag{54}$$

In computing the amplitude of Pt these components must be combined vectorially for each point calculated.

The expression for the amplitude of Pt is very simple for the special case of $\beta=0$ and $M=m$, and is

$$\frac{\pi E_p}{E} = MR_K \tag{55}$$

as may be readily verified by substituting the special conditions into (5) which then becomes

$$V = ER_K(1 + M \cos Pt). \tag{56}$$

Hence, there are no harmonics in this case, for any value of θ or of K which is allowed by (23). When $\beta=\pi$ the freedom from harmonics does not exist.

In Fig. 5 are shown plots of $\pi E_P/E$ vs θ for $M=m=0.3$ and $K=0.5$ for three values of β. E_P is the total resultant amplitude of the angular velocity P. For the extreme values of $\beta=0$ and $\beta=\pi$ this amplitude varies by 3:1 as the phase angle between the carriers changes by 180 degrees. The variation is considerably less for $\beta=\pi/2$. If there is a differ-

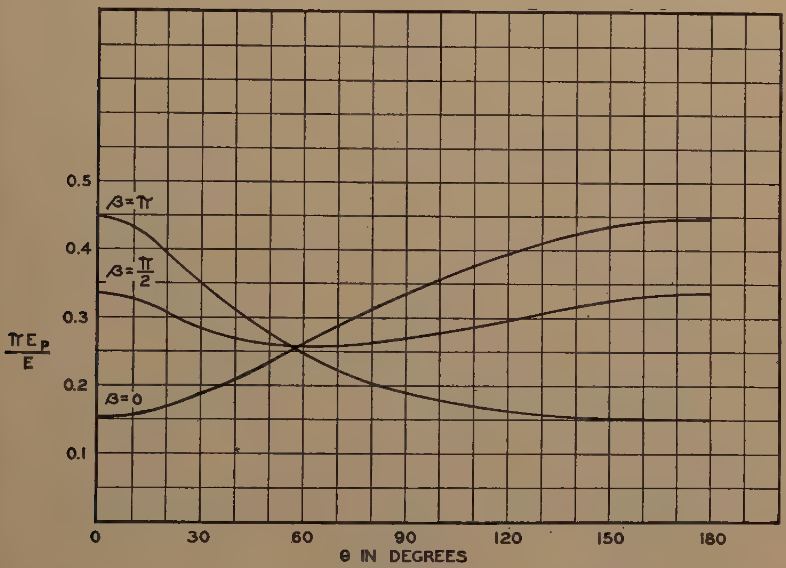


Fig. 5—Fundamental audio-frequency output when the carrier ratio is 0.5, and both carriers are modulated 30 per cent with the same radian velocity p. β is the phase angle between the modulating frequencies as defined by equation (3).

ence in the time of arrival of the modulating program at the two transmitting stations the value of β will be different for each frequency component of the program, and consequently the relative amplitudes of these components will be considerably altered when the two waves are detected. In Fig. 6 is shown a plot of the variation of $\pi E_P/E$ with β for $\theta=0$.

The expression for the second harmonic contains terms of only the second order in the m's since fourth-order terms have been neglected from the start. However, with $M=m=0.3$ the error is small. The terms in $2Pt$ are

$$-\frac{y_3}{4}\left[M^2 \cos 2Pt - 2mM \cos(2Pt+\beta) + m^2 \cos(2Pt+2\beta)\right]. \qquad (57)$$

If $M = m$ this reduces to

$$-\frac{M^2 y_3}{4}\left[\cos 2Pt - 2\cos(2Pt+\beta) + \cos 2(Pt+\beta)\right]. \tag{58}$$

If $\beta = 0$ this vanishes, as required by (56).
When $\beta = \pi$,

$$\left.\frac{\pi E_{2P}}{E}\right]_{\beta=\pi} = -M^2 y_3. \tag{59}$$

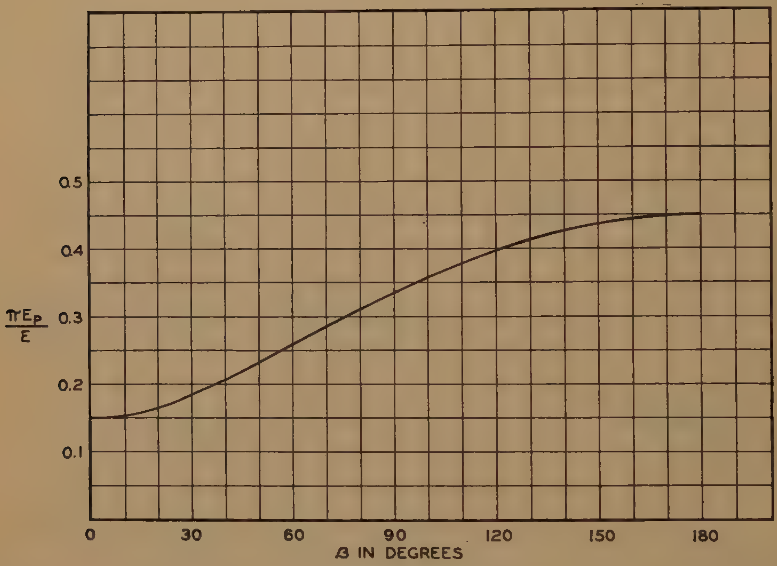


Fig. 6—Direct-current output voltage under conditions of Fig. 5 except that β is here the variable.

When $\beta = \pi/2$,

$$\left.\frac{\pi E_{2P}}{E}\right]_{\beta=\pi/2} = -\frac{M^2}{2} y_3. \tag{60}$$

The right side of (59) is the coefficient of $\cos 2Pt$, while (60) is the coefficient of $\sin 2Pt$, to which the terms in the brackets of (58) reduce when $\beta = \pi/2$.

Plots of the amplitudes of the second harmonic are shown in Fig. 7. A correlation of these curves with those of Fig. 5 shows that the second harmonic is of considerable importance when β is near π and θ is near 45 degrees.

Carrier Beat Not Zero

The expansions which have already been derived may readily be extended to cover the case in which the carrier beat is not zero. The

results obtained give formulas which are descriptive of the interference arising in shared channel, nonisochronous broadcasting. Such interference has already been discussed at length [3,5] but the present formulas are more convenient, and are rapidly convergent for a wider range of M, m, and K then are those developed in the earlier papers. There will be derived an expression which covers the general case of nonisochronous reception and several special cases of practical interest will then be discussed.

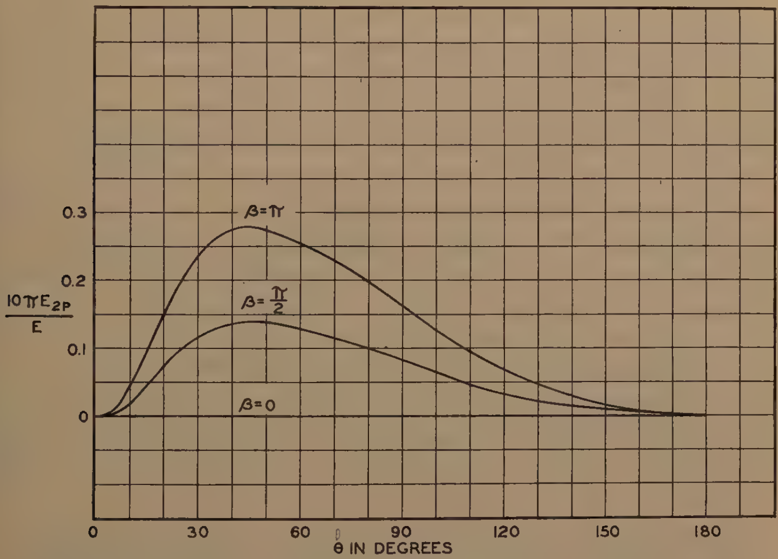


Fig. 7—Second harmonic of output voltage for conditions of Fig. 5.

The zonal harmonics which have appeared in our solutions are each finite polynomials of the form

$$P_q(\cos \theta) = L_0 + L_1 \cos \theta + L_2 \cos 2\theta + \cdots . \tag{61}$$

If q is even the terms with odd subscripts are zero and if q is odd the terms with even subscripts are zero. Expressions of this form are given on page 159 of Byerly's, "Fourier Series and Spherical Harmonics," for values of q up to 8, together with general formulas from which may be derived expressions for higher values of q.

When the carriers differ by an angular velocity of u radians per second we may set $\theta = ut$. By differentiating the expressions of the form of (61) with respect to θ, substituting ut for θ, and inserting the resulting expressions for P_q' (cos ut) into (22) there is obtained an expression from which may be readily extracted the desired frequency components. Thus,

$$
\left.
\begin{aligned}
\frac{V}{E} = {} & 1+\frac{K^2}{4}\,\frac{G_{20}}{2}\,\frac{a_{10}}{2}+\frac{K_4}{64}\,\frac{G_{40}}{2}\,\frac{a_{30}}{2}+\frac{K^6}{256}\,\frac{G_{60}}{2}\,\frac{a_{50}}{2}+\cdots \\
& -\left[K-\frac{K^3}{8}\,\frac{G_{30}}{2}\,\frac{a_{20}}{2}-\frac{K^5}{64}\,\frac{G_{50}}{2}\,\frac{a_{40}}{2}-\frac{5}{1024}\,\frac{G_{70}}{2}\,\frac{a_{60}}{2}\cdots\right]\cos ut \\
& -\left[\frac{K^2}{4}\,\frac{G_{20}}{2}\,\frac{a_{10}}{2}-\frac{K^4}{16}\,\frac{G_{40}}{2}\,\frac{a_{30}}{2}-\frac{5}{512}K^6\frac{G_{60}}{2}\,\frac{a_{30}}{2}\cdots\right]\cos 2ut \\
& -\left[\frac{K^3}{8}\,\frac{G_{30}}{2}\,\frac{a_{20}}{2}-\frac{5}{128}K^5\frac{G_{50}}{2}\,\frac{a_{40}}{2}-\frac{7}{1024}K^7\frac{G_{70}}{2}\,\frac{a_{60}}{2}\cdots\right]\cos 3\,ut \\
& -\left[\frac{mk}{2}-\frac{K^3}{16}G_{31}\frac{a_{20}}{2}-\frac{K^5}{128}G_{51}\frac{a_{40}}{2}-\frac{5}{2048}K^7G_{71}\frac{a_{60}}{2}\cdots\right]\cos(u\pm p)t \\
& +\left[\frac{K^3}{16}G_{32}\frac{a_{20}}{2}+\frac{K^5}{128}G_{32}\frac{a_{40}}{2}+\frac{5}{2048}K^7G_{71}\frac{a_{60}}{2}\cdots\right]\cos(u\pm 2p)t \\
& +\left[\frac{K^2}{4}G_{21}\frac{a_{10}}{2}+\frac{K^4}{64}G_{41}\frac{a_{30}}{2}+\frac{K^6}{256}G_{61}\frac{a_{50}}{2}+\frac{25K^8}{16384}G_{81}\frac{a_{70}}{2}\cdots\right]\cos pt \\
& +\left[\frac{K^2}{4}G_{22}\frac{a_{10}}{2}+\frac{K^4}{64}G_{42}\frac{a_{30}}{2}+\frac{K^6}{256}G_{62}\frac{a_{50}}{2}\cdots\right]\cos 2\,pt \\
& +\left[M+\frac{K^2}{4}\,\frac{G_{20}}{2}a_{11}+\frac{K^4}{64}\,\frac{G_{40}}{2}a_{31}+\frac{K^6}{256}\,\frac{G_{60}}{2}a_{51}\cdots\right]\cos Pt \\
& +\left[\frac{K^2}{4}\,\frac{G_{20}}{2}a_{12}+\frac{K^4}{64}\,\frac{G_{40}}{2}a_{32}+\frac{K^6}{256}\,\frac{G_{60}}{2}a_{52}\cdots\right]\cos 2\,Pt \\
& +\left[\frac{K^3}{16}\,\frac{G_{30}}{2}a_{21}+\frac{K^5}{128}\,\frac{G_{50}}{2}a_{41}+\frac{5K^7}{2048}G_{70}a_{61}\cdots\right]\cos(u\pm P)t \\
& +\left[\frac{K^3}{16}\,\frac{G_{30}}{2}a_{22}+\frac{K^5}{128}\,\frac{G_{50}}{2}a_{42}+\frac{5K^7}{2048}G_{70}\,a_{62}\cdots\right]\cos(u\pm 2P)t \\
& +\left[\frac{K^3}{32}G_{31}a_{21}+\frac{K^5}{256}G_{51}a_{41}+\frac{5K^7}{4096}G_{71}a_{61}\cdots\right]\cos(u\pm P\pm p)t \\
& -\left[\frac{K^2}{8}G_{21}\frac{a_{10}}{2}-\frac{K^4}{32}G_{41}\frac{a_{30}}{2}-\frac{5K^6}{1024}G_{61}\frac{a_{50}}{2}\cdots\right]\cos(2u\pm p)t \\
& -\left[\frac{K^2}{8}\,\frac{G_{20}}{2}a_{11}-\frac{K^4}{32}\,\frac{G_{40}}{2}a_{31}-\frac{5K^6}{1024}\,\frac{G_{60}}{2}a_{51}\cdots\right]\cos(2u\pm P)t \\
& -\left[\frac{K^2}{16}G_{21}a_{11}-\frac{K^4}{64}G_{41}a_{31}-\frac{5}{2048}K^6G_{61}a_{51}\cdots\right]\cos(2u\pm P\pm p)t \\
& -\left[\frac{K^2}{8}G_{22}\frac{a_{10}}{2}-\frac{K^4}{32}G_{42}\frac{a_{30}}{2}-\frac{5K^6}{1024}G_{62}\frac{a50}{2}\cdots\right]\cos(2u\pm 2p)t \\
& -\left[\frac{K^2}{8}\,\frac{G_{20}}{2}a_{12}-\frac{K^4}{32}\,\frac{G_{40}}{2}a_{32}-\frac{5}{1024}K^6\frac{G_{60}}{2}a_{52}\cdots\right]\cos(2u\pm 2P)t \\
& +\cdots\cdots\cdots\cdots\cdots\cdots
\end{aligned}
\right\}
\tag{62}
$$

a_{qn} and G_{qn} are given by Tables I and II, respectively. The ampli-
de of any component of output voltage is given by proper square
acket multiplied by $1/\pi$.

Equation (62) contains the complete story of the linear rectifica-
on of two modulated nonisochronous waves and is sufficient for the
scription of the numerous special cases which are of interest in vari-
is practical problems.

ffect of a Noise Background on the Reception of Shared Channel Signals

In listening to the signals received on shared channels it is often
oserved that, even though the modulation of the weaker station is
audible, there is an unpleasant "wobble" or "flutter" present. If the
eaker station employs deep modulation and there is no noise present
is condition will not exist but the modulation of the weaker station
ill become audible as "side band noise"[5] at a ratio of field strengths
ch that a flutter is absent. This has been previously pointed out.
owever if there is received a considerable amount of radio-frequency
oise then the presence of a weak carrier of a frequency slightly differ-
it from that of the desired carrier may cause very objectionable flut-
r even though the interfering signal is too weak to permit of the ob-
rvation of side band noise. For a given value of K, the ratio of the
idesired to the desired carrier, the magnitude of the noise flutter will
pend upon the type of detector used and will be much less serious
ien a linear detector is employed than it is when a square-law device
used.

In order to analyze the effect of noise when a linear rectifier is
ed we shall assume that there are impressed upon the detector a
sired signal $E(1+M \cos pt) \cos \omega t$ and a noise frequency $N \cos$
$+n)t$, $n/2\pi$ being an audible frequency. It will be assumed that
$/E$ is small as otherwise reception would be completely marred. The
tput resulting from the noise and desired signal will be determined,
d then the amplitude E, of the desired carrier, will be considered
vary slowly as the weak interfering carrier swings in and out of
ase with it.

Let,

$$k = N/E. \tag{66}$$

The output may be obtained from (62) by substituting k for K,
or u, and setting $m=0$. This last makes $G_{q0}/2=1$ and $G_{qn}=0$ for
≥ 1.

The components of (62) which start off with k^3 or higher powers are
tirely negligible since k is small. The other components are:

$$
\left.\begin{aligned}
&-\left[k-\frac{k^3}{8}\alpha^3\cdots\right]\cos nt\\
&-\left[\frac{k^2}{4}\alpha-\frac{k^4}{16}\left(1+\frac{M^2}{2}\right)\alpha^5\cdots\right]\cos 2nt\\
&+\left[\frac{k^2}{4}\alpha\mu-\frac{k^4}{32}3M\alpha^5\cdots\right]\cos(2n\pm P)t\\
&-\left[\frac{k^2}{4}\alpha\mu^2-\frac{k^4}{32}3M^2\alpha^5\cdots\right]\cos(2n\pm 2P)t
\end{aligned}\right\} \tag{67}
$$

in which α and μ are given below Table I, p. 608.

The component in nt is the most important. The output voltag amplitude of radian velocity n is

$$E_n=\frac{E}{\pi}\left[k-\frac{k^3}{8}\alpha^3\cdots\right] \tag{68}$$

$$=\frac{N}{\pi}\left[1-\frac{k^2}{8}\alpha^3\cdots\right]. \tag{68a}$$

Now if there is present a weak carrier that differs in phase from th desired carrier by an angle γ we may represent the total effective car rier by

$$\sqrt{E^2+e^2+2Ee\cos\gamma}$$

and if $e^2 \ll E^2$ this may be written

$$E+e\cos\gamma. \tag{69}$$

Hence,

$$E_n=\frac{N}{\pi}\left[1-\frac{N^2\alpha^3}{8(E+e\cos\gamma)^2}\right]$$

$$=\frac{N}{\pi}\left[1-\frac{k^2}{8}\alpha^3(1-2K\cos\gamma\cdots)-\right]$$

in which $K=e/E$

$$E_n=\frac{N}{\pi}\left[\left(1-\frac{k^2\alpha^3}{8}\right)+\frac{2k^2\alpha^3K}{8}\cos\gamma\right] \tag{70}$$

which can be written, to a close approximation, as

$$E_n=\frac{N}{\pi}\left[1+\frac{k^2\alpha^3K}{4}\cos\gamma\right]. \tag{70a}$$

If $\gamma = ut$, and u is small the amplitude of the noise will flutter, or obble. However, this effect will be very small since both k and K e small. Hence the noise of radian velocity u will cause little trouble ie to flutter.

Somewhat more flutter may be expected from the $2u$ component ice the amplitude of its variable portion is larger. Thus it is evident om (67) that to a first approximation

$$E_{2n} = \frac{N^2\alpha}{4\pi E}$$

id letting E vary as in (69) this becomes

$$E_{2n} = \frac{N}{\pi}\frac{\alpha k}{4}(1 - K\cos\gamma). \tag{71}$$

he steady part of this noise is smaller than the steady part of (70) a factor of $k\alpha/4$, which is small. However, the variable part of (70) smaller than the variable part of (71) by a factor $k\alpha^3$ which at low odulation of the desired carrier is equal to k.

The variable or flutter portions of the other terms of (67) are opreciable only at high modulations of the desired carrier and are not important as the variable portion of the amplitude of cos 2 nt. Even is flutter component is small and should be negligible except when e noise is severe. Hence, with a linear rectifier, the flutter due to a ght difference in the frequencies of the interfering and desired car-ers should generally be of less importance than the side band noise ie to the modulation of the interfering station even though noise be esent. Thus the ratio of the chief component of flutter amplitude, e., the coefficient of cos γ in (71)), to the amplitude of the desired equency $P/2\pi$ is

$$\frac{k^2K\alpha}{4M} \tag{72}$$

may be seen by comparing (71) with the cos Pt component of (62). or low modulations of the desired carrier (72) becomes

$$\frac{k^2K}{4M}. \tag{72a}$$

iis is very much smaller than the similar factor for a square-law tector which may readily be shown to be

$$\frac{kK}{M}. \tag{73}$$

Hence the flutter due to beat-in radio-frequency noise will be 4/ $=4E/N$ times as serious when a square-law detector is used as when linear detector is used. If the interfering carrier is weak and the carrie beat note is below the audible frequency range then there should b little or no flutter with the linear detector, while there may be a ver objectionable flutter when a square-law detector is used.

Another advantage of the linear detector under these conditions i that the distortion of the desired frequency $P/2\pi$, (the program fre quency), is very much less than that resulting from a square-law rect fier. This distortion is chiefly caused by the components of radia velocity $P+u$ and $P-u$ and it has already been pointed out[3] that thes components are much smaller when a linear rectifier is used.

This superiority of the straight-line detector, with regard to bot noise flutter and comparative freedom from distortion of the desire program by the action of the weaker interfering carrier, may readil be observed experimentally. If both types of detectors are arranged s that a rapid change may be made from one to the other, the compariso is very striking under many operating conditions.

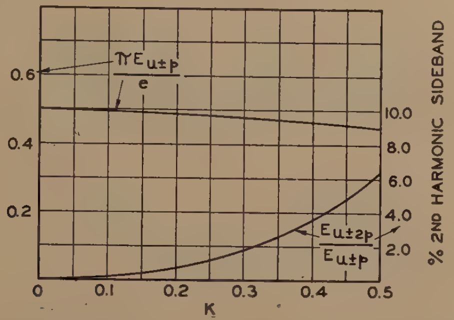
Other Special Cases

In addition to applications to shared channel broadcasting th formulas of this section are applicable to a description of the phe nomena involved in frequency translation, (heterodyne detection), an to the masking of a weaker signal by a stronger. Only brief considera tion will be given to these interesting phenomena since the latter ha already been discussed in print several times[2,3,4,6,8,9,10], and the forme is discussed in a very complete analytical treatment of the linear de tection of heterodyne signals, by E. B. Moullin.[9] This latter paper ap peared in print just as the present work was nearing completion an contains several of the formulas of this section. Moullin's method different from that here employed, and leads him to the conclusion tha the modulating and carrier beat frequencies must be small compare with the frequency of either carrier. From the discussion in the sectio "Set-Up of Problem" in the present paper it is evident that this r striction is unnecessary.

Frequency Translation

In Fig. 8 is shown the effect of the magnitude of the local unmodu lated carrier used in heterodyne detection upon the intermediate-fr quency output. The quantity shown is plotted as π times its rat to the amplitude e of the incoming carrier. The fundamental side ban varies only slightly for values of E/e ranging from 2 to ∞ (K rangin

rom 0.5 to 0). The change in the amplitude of ut, (not plotted), is lmost the same as that of $(u \pm p)t$, and hence the percentage modula-



'ig. 8—The linear rectifier as a heterodyne detector. The incoming carrier has an amplitude e and is modulated 100 per cent at a radian velocity p. The upper curve shows the ratio of the amplitude of one side frequency of the intermediate frequency output to e, as a function of $K = e/E$, the ratio of the amplitudes of the incoming and local carriers. The lower curve is the ratio, expressed as a per cent, of the side frequency differing from the intermediate-frequency carrier by $2p/2\pi$ to that differing from the intermediate-frequency carrier by $p/2\pi$.

ion is essentially constant. However, a second-order side band, (lower urve), is present, and amounts to six per cent of the first-order side and when $K = 0.5$.

Masking of Weak Signal

The modulation frequency output is much less than would be the ase if the stronger carrier were absent. This phenomena has been often iscussed and will not be treated at length here. None of the earlier nalyses are valid for a wide range of values of K and M except that f Moullin[9] who has developed expressions which cover the ground uite thoroughly.

We shall here employ the term "masking factor" to denote the ratio f the amplitude of pt to that which would occur with the same values f m and e for $E = 0$. This factor is:

$$\nu = \frac{K}{4m}\left[G_{21}\frac{a_{10}}{2} + \frac{K^2}{16} G_{14}\frac{a_{30}}{2} + \frac{K^6}{64} G_{61}\frac{a_{50}}{2} + \frac{25K^8}{4096} G_{81}\frac{a_{70}}{2} \cdots \right]. \quad (63)$$

 m and M are very small then,

$$G_{q1} = qm \quad \text{and} \quad \frac{a_{q0}}{2} = 1 \quad (64)$$

nd,

$$\nu_0 = \frac{K}{2}\left[1 + \frac{K^2}{8} + \frac{3}{64}K^4 + \frac{25}{2048}K^8 + \cdots \right]. \quad (65)$$

The value of ν_0 for $K=1$ is readily shown to be $2/\pi$. This value, and values computed for ν_0 for smaller values of K, are in agreement with the results given by Butterworth's formula but do not entirely agree with the table in his paper[2] which contains numerical errors.

When m is not small then (63) is the correct expression although the difference is not great. For example when $K=0.5$, $M=0$, and $m=0$, $\nu=0.259$; while when $K=0.5$, $M=0$, and $m=1$, $\nu=0.290$.

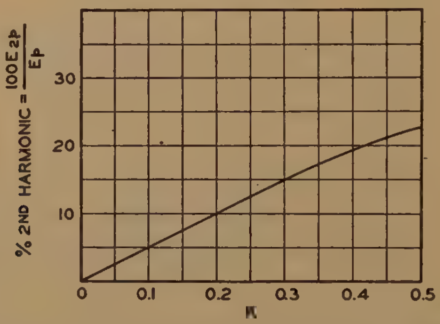


Fig. 9—Harmonic distortions occurring in the detection of a 100 per cent modulated weak signal in the presence of a strong unmodulated carrier.

The distortion of the received signal may be considerable as is indicated by Fig. 9 which shows the per cent second harmonic as a function of K for 100 per cent modulation of the weak signal.

Appendix A

β and γ both depend upon the difference in length of the transmission paths between the receiving point and the two transmitting stations. In addition to this, β depends upon the phase difference of the modulating frequency impressed upon each transmitter, it being assumed that the modulating frequency is the same at each station. γ is dependent upon the difference in phase of the carrier waves leaving the two stations as well as upon the path difference.

Let the distance from the receiving point to one of the stations be d_1 and to the second station be d_2. Let the phase of the carrier wave leaving the first station be arbitrarily taken as zero and let the phase of the second carrier, as it leaves its station, lead the first carrier by the angle γ'. If the same modulating frequencies are employed assume that that which is impressed upon the first station has phase zero and that impressed upon the second station leads the first by an angle β'. Then it is evident that the signal radiated from the first station is

$$E[1 + M \cos Pt] \cos \omega t$$

while that from the second station is

$$e[1 + m \cos (\omega t + \beta') \cos (\omega t + \gamma')].$$

In traveling the distance d_1 the signal from the first station will be retarded by the time d_1/c, c being the velocity of propagation of the wave. The carrier and side bands arriving at the receiver will then be expressed by

$$E \cos \omega(t - d_1/c) + \frac{EM}{2} \cos [(\omega + P)(t - d_1/c)] + \frac{EM}{2} \cos [(\omega - P)(t - d_1/c)].$$

In a like manner the signal received from the second station is

$$e \cos [\omega(t - d_2/c) + \gamma'] + \frac{em}{2} \cos [(\omega + P)(t - d_2/c) + \gamma' + \beta'] + \frac{em}{2} \cos [(\omega - P)(t - d_2/c) + \gamma' - \beta'].$$

Since only relative phase is of importance the origin of time may be shifted so as to replace t by $t+d_1/c$. If this is done in the above expressions it follows that the wave received from the first station may be written

$$E(1 + M \cos Pt) \cos \omega t$$

while that received from the second station is

$$e(1 + m \cos [P(t - D/c) + \beta']) \cos [\omega(t - D/c) + \gamma'],$$

in which $D = d_2 - d_1$.

Now let,

$$\gamma = \gamma' - \omega D/c \quad \text{and} \quad \beta = \beta' - PD/c.$$

The signal received from the second station is then simply

$$e[1 + m \cos (Pt + \beta)] \cos (\omega t + \gamma)$$

and the two signals are of the form of equation (3) of the text. It is evident that if the analysis is made in terms of γ and β then the effect of position of the receiver with respect to the transmitters can be brought in at any time by reference to the simple relation between β and β' and between γ and γ'. Hence the analysis in terms of β and γ is general and is not restricted to special space relations between transmitters and receiver.

Appendix B

In order to prove that the phase angle δ, which is defined by (6), may be neglected let us note that, according to Weirerstrass' theorem, it is possible to represent any continuous, single valued function to any desired degree of approximation by means of a finite power series.* By including a sufficient number of terms the accuracy can be made as great as may be desired. Hence the rectified output of a linear detector, as well as detectors having characteristics represented by Taylor's series, can be obtained by substituting (7) into a power series development and selecting the direct-current and low-frequency terms.

Now $\cos^n(\omega t+\delta)$ may be expanded into a polynomial containing terms of the form $\cos\mu(\omega t+\delta)$ in which μ may be $0, 1, 2 \cdots$.

$$\cos\mu(\omega t+\delta) = \cos\mu\omega t\cos\mu\delta - \sin\mu\omega t\sin\mu\delta. \tag{B1}$$

Now $\cos\mu\delta$ and $\sin\mu\delta$ can be expanded into multiple Fourier series, that is, series in several variables. If for the sake of generality, we assume that the carrier waves are of different frequency then $\gamma = ut$ and these series will contain sinusoidal terms in ut, Pt, pt and the various multiples, sums, and differences of these quantities. It is now evident that all odd powers of $\cos(\omega t+\delta)$ will contribute only radio frequencies, that is radian velocities $\mu\omega$, $(\mu\omega\pm\nu\mu)t$, $(\mu\omega\pm\lambda P)t$, etc., but no terms of the order of ut, Pt, pt, etc. Even powers of $\cos(\omega t+\delta)$ will similarly yield radio-frequency terms, and in addition each such power will yield a constant term. These constant terms will obviously not contain δ since the constant part of $\cos^n(x+\delta)$ = constant part $\cos^n x$. The only low-frequency contributions will then result from the products of these constant terms with their associated powers of V, and these products will not contain δ. Hence the neglecting of δ introduces no error whatever into the derivation of the expressions for the terms which do not contain ω. In the present case this includes the low-frequency and direct-current terms.

Of course if some of the side bands of the radio-frequency terms fall in the same range as the frequencies resulting from the analysis of the amplitude then such side frequencies will modify the output. The significance of such a case is obvious and in no way affects the foregoing argument. Furthermore, it is evident by physical intuition that no appreciably large side bands of the radio-frequency terms or their harmonics will fall in the audio-frequency range.

The above reasoning can readily be extended to cover the case in which more than two waves are combined into a single wave of variable phase and amplitude.

* *See* Courant und Hilbert, "Methoden der Mathematische Physik," vol. I, 2nd edition, pages 55–57.

Bibliography

1. W. B. Medlam and U. A. Oschwald, "The performance of valve detectors," *Jour. Inst. Wireless Tech.*, vol. 1, pp. 147–223, (1928).
2. S. Butterworth, "Note on the apparent demodulation of a weak station by a stronger one," *Exp. Wir. & Wir. Eng.*, vol. 6, pp. 619–621; November, (1929).
3. C. B. Aiken, "Detection of two modulated waves which differ slightly in carrier frequency," Proc. I.R.E., vol. 19, pp. 120–137; January, (1931).
4. F. M. Colebrook, "A further note on the apparent demodulation of a weak station by a stronger one," *Exp. Wir. & Wir. Eng.*, vol. 8, pp. 409–412; August, (1931).
5. C. B. Aiken, "Further notes on the detection of two waves which differ slightly in carrier frequency," Proc. I.R.E., vol. 20, pp. 569–578; March, (1932).
6. Appleton and Boohariwalla, "The mutual interference of wireless signals in simultaneous detection," *Wir. Eng. & Exp. Wir.*, vol. 9, pp. 136–139; March, (1932).
7. F. M. Colebrook, "The frequency analysis of the heterodyne envelope," *Wir. Eng. & Exp. Wir.*, vol. 9, pp. 195–201; April, (1932).
8. E. Mallett, "'Apparent demodulation' another viewpoint," *Wir. Eng. & Exp. Wir.*, vol. 9, pp. 248–252; May, (1932).
9. E. B. Moullin, "The detection by a straight line rectifier of modulated and heterodyne signals," *Wir. Eng. & Exp. Wir.*, vol. 9, pp. 378–383; July, (1932).
10. F. M. Colebrook, Letter to the Editor, *Wir. Eng. & Exp. Wir.*, vol. 9, p. 394; July, (1932).

Proceedings of the Institute of Radio Engineers
Volume 21, Number 4 *April, 1933*

DISCUSSION ON "SOME NOTES ON GRID CIRCUIT AND DIODE RECTIFICATION"*

F. E. Terman and J. R. Nelson

Fred G. Kelly:[1] As a nonmember reader of the Institute's Journal I have had occasion to refer to your more recent articles on the diode-rectification method of detection of radio-frequency signals. The complete theoretical treatment and experimental verification available in articles over the past few years, the latest of which to date are the excellent discussions by Messrs. F. E. Terman and J. R. Nelson,* have been very helpful.

However, I noticed that to date this method of detection has one shortcoming, specifically that it cannot help but distort at 100 per cent modulation and thereabouts. Dr. Terman expressed it in his December discussion in a statement to the effect that for distortionless detection the ratio X/R must theoretically equal infinity, where X is the grid condenser reactance and R the leak resistance. I have used a circuit with a slight change from Dr. Terman's in which there is no distortion theoretically or practically up to and including 100 per cent modulation, and yet in which X/R theoretically does not need to be quite as high as would ordinarily be used. I submit an explanation below with the hope that the modification which to my knowledge is new, will be of interest to Messrs. Terman, Nelson and other members.

Theoretically, the ideal grid leak for a detector would be a constant-current device from zero applied voltage to the highest. This could cause a constant discharge rate for the condenser-leak combination, which for distortionless detection would be made to equal the maximum slope of carrier envelope to be encountered at all percentages of modulation.

Of course, there is no such constant-current leak practical, but if the ordinary leak be disconnected at the cathode of the rectifier and reconnected to a point on the direct-current supply positive with respect to the cathode by several times the peak of the rectified envelope, the leak current may be made very nearly constant as the bias fluctuations are then only a small part of the total voltage across the leak. Of course the resistance of the leak should then be increased to bring its average direct current back to what it was before.

As an example, suppose a diode detector is to be designed for usual broadcast carrier frequencies to detect without distortion all audio frequencies up to 5000 cycles and up to 100 per cent modulation, but with maximum instantaneous envelope slope not to exceed 20,000 volts per second. Assume a value of C of 0.00025 microfarad, a maximum negative peak for C of five volts, and a positive tap for the leak of $22\frac{1}{2}$ volts above the cathode potential. Then the discharge rate of C by R must be equal to 20,000 volts per second, so we have

$$20{,}000 = \frac{22.5 + 5/2}{0.00025 \times 10^{-6} \times R}$$

or,

$$R = 5 \times 10^6 \text{ ohms.}$$

There appears to be no disadvantage in connecting the leak from bias to positive instead of to ground unless a positive potential on the detector bias during starting before the detector cathode has become warm is so considered. The current in such case, as the cathode heated, would be hundreds of times less than the plate current during heating transients.

* Proc. I.R.E., vol. 20, no. 12; pp. 1971–1974; December, (1932).
[1] Eastern Engineering Company, New Haven, Connecticut.

Proceedings of the Institute of Radio Engineers
Volume 21, Number 4 *April, 1933*

BOOK REVIEWS

Radio Engineering Handbook, by Kieth Henney, editor in chief, and twenty-two collaborators. Published by McGraw-Hill Book Company. 583 pages, size 5″×7¾″. Flexible binding. Price $5.00.

The last decade has seen the activities of radio engineers diverted into many associated fields. To attempt to become specialized in more than a few subjects is hardly practicable and so it becomes necessary to have information readily available concerning other branches of the radio field, in order to coördinate developments with those in other lines.

This book follows the style of the well-known electrical handbooks in that each of the various sections was compiled by an authority in that field. The twenty-three sections start with mathematical tables frequently referred to, and continue through circuit theory into the sections devoted to particular equipment. The arrangement of the subjects and the correlation of the various sections represents painstaking work.

A critical review of all the subject matter is hardly possible for a single reviewer, due to the wide list of subjects handled. In general, each section is devoted to a survey of present-day practices, with data, circuits, curves, and such basic mathematics as are necessary. The book is not padded with extensive descriptions of equipment or photographs, since the general appearance of most apparatus is fairly well known. It is recommended as a reference book to executives, engineers, operators, service men, amateurs,—anyone who has anything to do with radio apparatus.

*R. R. Batcher

Report of the Radio Research Board for the Year 1931. 123 pages, 31 figures, paper binding. Published by His Majesty's Stationery Office, London. Price 2s. 0d. net.

This is a detailed review of the work of the British Radio Research Board for the year 1931. Copies of the report became available in December, 1932. The work included studies of wave propagation, directional radio, atmospherics, antennas for transmission and reception, electron oscillations giving rise to waves less than a meter in length, frequency standards, electrical measurements at radio frequencies, interference, and several miscellaneous problems. A list of publications is included.

The wave propagation work included experimental studies of the ionization of the upper atmosphere by the frequency-change method and the pulse method. Theoretical studies of this ionization were also made. The propagation of waves at frequencies above 30,000 kilocycles was studied, both at very short distances and at the greatest distances over which communication could be established.

Improvements are described in modified Adcock antennas which were developed for directional reception. Both large fixed antennas and small rotatable antennas of this type were used.

* Hollis, L. I., N. Y.

A graphical method for determining the field intensity in the neighborhood of an antenna was developed and extended to take account of the electrical constants of the earth. The field distribution in a vertical plane of single antennas and arrays was studied.

The pen-writing atmospherics recorder was further developed into a narrow sector recorder, removing the 180-degree ambiguity. The technique of photographic registration at two stations of individual atmospherics made possible the determination of the sources of individual atmospherics.

Work was proceeding on the development of a 20-kilocycle quartz oscillator frequency standard. The tuning fork standard in use was found accurate, hour by hour and day by day, to one part in five million. Work was in progress to determine the short-period constancy of the fork.

A number of problems on radio-frequency measurements, interference and miscellaneous subjects are also reviewed. This report is an excellent summary of the important investigations of this group of research workers.

*S. S. Kirby

Acoustics and Architecture, by Paul E. Sabine, McGraw-Hill Book Company, New York, N. Y., 327 pages. Price $3.50.

One reason for the publication of this book is evidently to provide the architect with some knowledge of acoustics. With this in mind, the author has greatly simplified the theory, and in the first few chapters there is found a very elementary treatment of the nature and properties of sound, stationary waves in tubes, and vibrations of air columns.

The theoretical treatment of reverberation is carried out for the case of a closed tube and then extended to apply to a room, for which case the simple reverberation formula is deduced. For the experimental determination of reverberation time, the author describes the method developed by Wallace Sabine, making use of the threshold of audibility of the human ear. The description of the more modern electrical methods are not given until a later chapter dealing with the measurements of absorption coefficients of materials. These measurements are described in great detail and comparisons are given for various methods of test.

Auditorium design receives much attention in the book. Typical numerical problems are worked out in detail to indicate the method of computing reverberation in rooms. The correct reverberation times for movie studios, broadcast studios, recording rooms, etc., are discussed. The shape of the auditorium and its effect on the acoustics is also mentioned, as well as several examples of good and bad auditoriums. Unfortunately, nothing is said regarding the use of public address systems.

Noise measurement and its reduction are described. Here the author cites two methods of measurement, namely, the tuning fork method and the audiometer, both depending on the characteristic of the human ear, and neglects to mention the more modern sound meters which give direct instantaneous readings of sound intensities.

Several methods for the measurement of sound transmission through walls are described, and very complete data are given on the efficiency of various structures for the insulation of sound.

* Bureau of Standards, Washington, D. C.

The last chapter on the isolation of machinery is well treated. Oscillograms are included showing the vibrations transmitted from the machine to the floor and the attenuation of these vibrations resulting from various mountings. Among the tabulated information in the appendixes are the absorption coefficients (from 128 cycles to 4096 cycles) of 41 samples of building materials recently tested at the Riverbank Laboratories. Another table is also included showing the results obtained by other authorities on 52 samples.

*FRANK MASSA

* RCA Victor Co., Inc.

RADIO ABSTRACTS AND REFERENCES

THIS is prepared monthly by the Bureau of Standards,* and is intended to cover the more important papers of interest to the professional radio engineer which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the "Classification of Radio Subjects: An Extension of the Dewey Decimal System," Bureau of Standards Circular No. 385, obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents a copy. The classification also appeared in full on pp. 1433–1456 of the August, 1930, issue of the PROCEEDINGS of the Institute of Radio Engineers.

The articles listed are not obtainable from the Government or the Institute of Radio Engineers, except when publications thereof. The various periodicals can be secured from their publishers and can be consulted at large public libraries

R000. RADIO (GENERAL)

R010 Recent radio research. *Nature* (London), vol. 131, pp. 156–157; February 4, (1933).

A summary is given of the report of the Radio Research Board for the year 1931.

R020 The principles of electromagnetism (editorial). *Wireless Engineer & Experimental Wireless* (London), vol. 10, pp. 61–64; February, (1933).

A review of E. B. Moullin's book. After discussing at length the features of the book with which the author does not agree, it is emphasized that the greater part of the book contains standard material treated in an admirable manner.

R090 Electrical communication in 1932. *Electrical Communication,* vol. 11, pp. 113–127; January, (1933).

A survey of the progress made in electrical communication in 1932.

R090 J. E. Taylor. Notes on wireless history. *Post Office Electrical Engineers Journal* (London), vol. 25, pp. 295–299; January, (1933).

A brief historical survey of radio development.

R100. RADIO PRINCIPLES

R100×R020 F. E. Terman. Radio engineering (book). Published 1932 by McGraw-Hill Book Co., New York, N. Y. $5.00 per copy.

The reviewer considers the book a good nonmathematical treatment for the radio engineer.

R113 S. Namba. General theory on the propagation of radio waves in the ionized layer of the upper atmosphere. PROC. I.R.E., vol. 21, pp. 238–262; February, (1933).

Theories on the propagation of radio waves in the entire range of frequencies used in communications are treated together with discussions on the applicable limit of the theory of geometrical optics to wave propagation.

* This list compiled by Mr. A. H. Hodge and Miss E. M. Zandonini.

R113.2 E. Yokoyama and I. Tanimura. Some long-distance transmission phenomena of low-frequency waves. Proc. I.R.E., vol. 21, pp. 263–270; February, (1933).

From the results of a series of twenty-four-hour receiving measurements conducted for more than two and a half years, some interesting phenomena are picked out and discussed. The main points of the conclusions reached are: (1) the daylight signal strength of Kahuku is greater than the night signal strength; (2) several successive crevasses of about a two hours' period are observed regularly in the signal strengths of Bolinas and Kahuku during the partial daylight hours.

R113.55 E. T. Burton and E. M. Boardman. Effects of solar eclipse on audio frequency atmospherics. *Nature* (London), vol. 131, pp. 81–82; January 21, (1933).

Observations made during and before the eclipse of August 31, 1932 indicate an approach to nighttime intensity near the period of totality. Data on resonance tone indicate an approximation to evening conditions before and during totality, followed by a condition similar to that of morning. The data are considered as evidence of a corpuscular radiation although only a minor effect is observed.

R125 S. Chiba, S. Taki, and S. Ito. A study of ultra-short wave directive antennae. *Reports of Radio Researches and Works in Japan*, vol. 2, p. 8; September, (1932).

As types of untuned beam antennas, the Beverage wave antenna and the Yagi-Uda wave director were tested on 84-centimeter waves. As types of tuned arrays, a zigzag system for vertically polarized 84-centimeter waves and a vertical plane horizontal doublet system for horizontally polarized 50-centimeter waves, were tested, with particular attention to their behavior when used simultaneously on the same set. "The vertical and the horizontal waves are projected with no appreciable mutual interference with each other."

R125 T. Tsukada. An improved goniometer-type direction finder for high-frequency waves using Adcock aerials and a divided search coil. *Reports of Radio Researches and Works in Japan*, vol. 2, p. 8; September, (1932).

The rotating search coil is divided into two parts electrically connected in series and set at right angles to each other. There are two antenna coils each within its shielded chamber and each coupled to one part of the search coil. Two sets of Adcock-type antennas are used. Stray couplings between the two antenna coils are thus entirely eliminated and successful direction finding on high frequencies can be carried out.

R131 G. F. Eonda, A. H. Young, and A. Walker. The diffusion of thorium in tungsten. *Physics*, vol. 4, pp. 1–6; January, (1933).

Thoriated tungsten wires were heat treated in gas to develop variations in grain size. These variations produced marked variations in thermionic emission characteristics. Experiments are described which demonstrate the spreading of thorium over a single crystal of tungsten and which manifest the effect of slight strains in the lattice upon activation.

R131 Non-linear valve characteristics—A brief discussion on their use. *Wireless Engineer & Experimental Wireless* (London), vol. 10, pp. 83–88; February, (1933).

In this article a method is given for showing how the frequencies in an input signal are added and subtracted by a curved input characteristic. Simple rules are given for determining the effective combination of frequencies, and modulation rise, cross modultion, detection, modulation and high-frequency mixing are considered in detail.

R132 F. M. Colebrook. Voltage amplification with high selectivity by means of the dynatron circuit. *Wireless Engineer & Experimental Wireless* (London), vol. 10, pp. 69–73; February, (1933).

It is shown analytically that a tetrode vacuum tube used as a dynatron is more selective than the tuned circuit alone, and the voltage amplification is comparable to that given by the vacuum tube used in the normal manner. A high degree of feedback is necessary to make the vacuum tube operating normally have a sensitivity comparable to that of the dynatron.

R132 L. B. Turner. Wireless Section: Chairman's address. *Jour. I.E.E.* (London), vol. 72, pp. 10–30; January, (1933).

This address, delivered November 2, 1932, is divided into two parts. Part 1 sets forth the various properties of thermionic vacuum tubes and reviews the forms of high vacuum tubes that have been developed. Part 2 deals at length with the obstacles to the amplification of extremely weak signals. The shot, flicker, and temperature or Johnson effects are considered.

R138 F. Hamacher. Über die räumliche Verteilung der Emission von Glühkathoden. (On the space distribution of emission from hot cathodes.) *Archiv für Elektrotechnik*, vol. 37, pp. 47–56; January, (1933).

By observing the fluorescence on a screen which served as an anode, the emission distribution of a hot cathode was determined.

R140 J. G. Brainerd. Relations between the parameters of coupled-circuit theory and transducer theory with some applications. Proc. I.R.E., vol. 21, pp. 282–289; February, (1933).

Relations between the impedance parameters usually used in coupled-circuit theory and those of transducer theory are derived. These indicate some useful methods of attacking certain problems—the determination of resonance conditions in a chain of coupled circuits, for example.

R140 A. Hikosaburo. Ellipse diagram of a Lecher wire system. Proc. I.R.E., vol. 21, pp. 303–311; February, (1933).

The nature of the ellipse diagram is explained in detail in this paper. By the aid of this diagram, the effect of the length of the wires on the form of the current through the end of Lecher wire system is investigated.

R141.2 R. Lee. A practical analysis of parallel resonance. Proc. I.R.E., vol. 21, pp. 271–281; February, (1933).

Vector diagrams are developed for various conditions of tuning parallel circuits, and from the geometry of the diagrams mathematical relations are derived. These relations are then plotted for use in tuning operations. Two examples are given of the practical application of the analysis.

R200. Radio Measurements and Standardization

R214 G. A. Tomlinson. A new type of free-pendulum clock. *Proc. Phys. Soc.* (London), vol. 45, pp. 41–48; January, (1933).

A method of taking accurately defined seconds signals from a pendulum is described, in which a photo-electric cell is used in conjunction with a special arrangement of multiple slits. This has been developed into a complete free pendulum system self maintained in vacuum by means of electrostatic impulses and having a closely governed arc.

R241 A. H. Lynch. The why and wherefore of low and high-resistance ohmmeters. *RadioCraft*, vol. 4, p. 535; March, (1933).

A comprehensive description of fundamental principles governing the choice and calibration of ohmmeters suitable for low- and high-resistance measurements.

R243.1 C. H. W. Nason. A survey of the vacuum-tube voltmeter field. *RadioCraft*, vol. 4, pp. 543–45; March, (1933).

Detailed article dealing with the construction of various types of vacuum tube voltmeters suitable for various classes of service.

R243.1 ×R363 H. Sohon. Supervisory and control equipment for audiofrequency amplifiers. Proc. I.R.E., vol. 21, pp. 228–237; February, (1933).

This paper is divided into two parts: In the first part a new type of level indicator is presented, and in the second part a device for controlling the output signal of an amplifier is described.

R270 D. H. Macne. Special noise testing equipment. *Electrical Communication*, vol. 11, pp. 128–134; January, (1933).

A noise testing apparatus consisting of high gain amplifiers, resonant wave analyzers, variable or fixed frequency oscillators, thermomilliammeter sets, attenuators, search coils, etc., is described.

R270 G. C. DeCoutouly. Portable long wave testing apparatus. *Bell Laboratories Record*, vol. 11, pp. 178–183; February, (1933).

Description of a portable field intensity set.

R300. Radio Apparatus and Equipment

R300 R. S. J. Spilsbury. Meter and instrument section: Chairman's address. *Jour. I.E.E.* (London), vol. 72, pp. 30–36; January, (1933).

An outline is given of the equipment and methods which are employed at the National Physical Laboratory for the testing of alternating-current instruments for power frequencies.

R330 The filamentless tube. *RadioCraft*, vol. 4, pp. 528–529; March, (1933).

A description is given of the filamentless tube and its method of operation.

R330 J. O. McNally. A "low-hum" vacuum tube. *Bell Laboratories Record*, vol. 11, pp. 158–162; February, (1933).

The development and characteristics of the Western Electric No. 262-A vacuum tube are discussed.

R330 ×R331 New amplifiers—Detectors and rectifiers. *Electronics*, vol. 6, p. 35; February, (1933).

Characteristics of the following vacuum tubes are given: Type: 53, 75, 77, 78, 79, 90, 92, 2A3, 2A5, 2A7, 2B7, 6A7, 6B7, 84, 96, 98, 5Z3, 25Z5, ER1, HZ50.

R339 J. F. Dreyer. Gaseous discharge tubes for radio receiver use. *Electronics*, vol. 6, pp. 40–42; February, (1933).

The use of gaseous discharge vacuum tubes as aids to tuning receivers is discussed.

R355.2 British Broadcasting Company long-wave station. *Electrician* (London), vol. 110, p. 63; January 20, (1933).

Contract is placed for high-power transmitter at Droitwich—Tubes with input of 500 kilowatts.

R355.21 A. W. Kishpaugh and R. E. Coram. Low power radio transmitters for broadcasting. Proc. I.R.E., vol. 21, pp. 212–227; February, (1933).

This paper discusses the place of low powered installations in the existing radio broadcast system, and the importance of apparatus for such stations meeting the present-day requirements pertaining to frequency stability, modulation capability, fidelity, and radio-frequency harmonics. The characteristics and more interesting features of a new line of transmitters covering the range of output from 100 to 1000 watts are described.

R355.9 A. E. Thiessen. A signal generator for the new receiver tests. *Radio Engineering*, vol. 13, pp. 14–16; January, (1933).

After describing the "two signal generator" tests that are made on receivers, a standard signal generator type 603-A is described. This instrument is flexible and is said to be quite adequate for receiver testing as well as other types of work.

R356.3 ×621.374.31 H. W. Hartmann. Thyratron controlled voltage rectifiers. *Electronics*, vol. 6, p. 43; February, (1933).

A circuit is treated which uses a Selsyn transformer to vary phase relation between the grid and plate voltages of the thyratron tubes. This provides a 100 per cent, uniform regulation of the direct-current voltage.

R356.3 P. R. Sidler. Metal-clad mercury-arc rectifiers in broadcast stations. *Radio Engineering*, vol. 13, pp. 10–11; January, (1933).

Descriptions are given of several metal-clad mercury-vapor rectifiers of high power rating. Several advantages of this type of rectifier are given.

R363 W. Baggally. Grid current compensation in power amplifiers. *Wireless Engineer & Experimental Wireless* (London), vol. 10, pp. 65–68; February, (1933).

The problem of designing an amplifier that will be free from grid current distortion is discussed. A practical example is treated. A method of calculating the optimum load and power output of a grid current amplifier is given.

R363.2 C. C. Whitehead. Output stages—The choice of valves for use in low-frequency amplifiers. *Wireless Engineer & Experimental Wireless* (London), vol. 10, pp. 78–82; February, (1933).

A brief résumé is given of an article by B. C. Brain. The author then extends this work and devises a test for power vacuum tubes to determine the suitability for use in an output stage of any given amplifier. The following problems are solved; (1) the minimum anode voltage required to obtain a given output and efficiency; (2) whether a reasonable efficiency is obtainable without exceeding the maximum anode voltage recommended by the makers.

R365.21 I. Wolff and J. I. Cornell. Acoustically compensated volume control. *Electronics*, vol. 6, pp. 50–51; February, (1933).

A circuit arrangement is described which is intended to compenate for the deficiencies of the frequency characteristic of the human ear, and to provide a sound pressure frequency characteristics of the output of the receiver which varies inversely with the ear frequency characteristic.

R381 P. R. Coursey. Electrolytic condensers—Their properties and uses. *Wireless World*, vol. 32, pp. 24–26; January 13, (1933).

This article describes the construction of electrolytic condensers of various types and gives the reasons for their employment in special cases.

R382 S. W. Place. Design of radio-frequency coils. *Radio Eng.*, vol. 13, pp. 12–13; January, (1933).

The following subjects are briefly treated: design of coil, matching, radio-frequency resistance, dielectric losses.

R382.1 M. Pawley. The audio transformer as a selective amplifier. *Jour. Frank. Inst.*, vol. 215, pp. 133–147; February, (1933).

A selective amplifier is developed. It utilizes an audio transformer with a variable series resistance in the primary circuit, and a variable secondary load capacitance both of which may be adjusted to give broad or narrow peaked amplification at any frequency within a wide range, or flat amplification throughout this range.

R382.1 W. D. Grant. Light weight transformers for aircraft. *Bell Laboratories Record*, vol. 11, pp. 173–177; February, (1933).

Description of apparatus.

R385.5 Velocity microphones. *QST*, vol. 17, pp. 23–25; February, (1933).

Constructional details of the direct-current field type and the permanent magnet type microphones.

R387 C. Stansbury and G. C. Brown. An electronic phase-failure relay. *Electronics*, vol. 6, pp. 46–47; February, (1933).

The advantage of electronic apparatus over the usual mechanial relays is given. The electron tube circuit and method of operation is discussed.

R388 H. Hartridge. A method of extending the frequency range of the cathode-ray tube. *Nature* (London), vol. 131, pp. 95–96; January 21, (1933).

A long focus collimating lens receives light from the cathode-ray tube and renders the rays parallel. A short focus cinema lens of large aperture receives these parallel rays and focuses them onto the photographic emulsion.

R400. Radio Communication Systems

R423.5 Ultra-short radio waves and the Cardiff-Weston-Super-Mare radio link. *Post Office Electrical Engineers Journal* (London), vol. 25, pp. 303–306; January, (1933).

An experimental communication system using the frequency range 3–10 meters is described.

R430 A. J. A. Gracie and E. J. C. Dixon. Carrier noise in short-wave transmitters. *Post Office Electrical Engineers Journal* (London), vol. 25, pp. 300–303; January, (1933).

Unwanted modulation of the carrier frequency of short-wave transmitters may originate in the frequency control stages from ripple on the power supply. It is shown that the percentage modulation may be increased at single vacuum-tube frequency multiplier stages operated so as to produce the largest second harmonic content in the anode circuit. It is shown that the modulation may be eliminated by saturation at the doubler stages.

R430 P. P. Eckersley. The required minimum frequency separation between carrier waves of broadcast stations. Proc. I.R.E., vol. 21, pp. 193–211; February, (1933).

The general problem of interference between adjacent broadcast channels is discussed in relation to the average distribution of power over the frequency range of typical broadcast signals, the response characteristics of the ear, and the frequency characteristics of transmitters and receivers. The conclusions suggest that some rather extensive changes in the frequency allocation of broadcast channels will be necessary in order to provide at least one clear channel capable of high-quality program transmission to all receivers.

R500. Applications of Radio

R566 H. E. Thomas. The development of police motor-car radio. *Radio Eng.*, vol. 13, pp. 20–21; January, (1933).

The general features of police radio are given. These include circuit design, sensitivity, adjustments, power demands, etc.

R800. Nonradio Subjects

537.65 V. Petržilka. Längs- und Beigungsschwingungen von Turmalinplatten. (Length and transverse vibrations in tourmaline plates.) *Annalen der Physik*, vol. 15, pp. 881–901, (1932).

A theoretical analysis with 36 plates.

537.65 G. W. Fox and M. Underwood. On the piezo properties of tourmaline. *Physics*, vol. 4, pp. 10–13; January, (1933).

Oscillating piezo-electric plates of different frequencies were made from California and South African tourmaline. Frequency response was 3770 kilocycles per millimeter of thickness. Temperature coefficient −33.5 parts per million per degree Centigrade for African and 38.1 parts for California crystal. Compared to quartz they were found to be inferior on the basis of power output.

621.319.2 ×R116 H. Roder. Graphical methods for problems involving radio-frequency transmission lines. Proc. I.R.E., vol. 21, pp. 290–302; February, (1933).

Neglecting resistance and leakage conductance of the line, graphical methods are given for the determination of currents, voltages, and impedances along a transmission line. A simplified elliptical diagram is developed for finding current or voltage distribution. The application of circle diagrams is explained, by means of which the line input impedance may be obtained under various conditions.

621.375.1 Electron tubes in Radio City theatres. *Electronics*, vol. 6, pp. 32–34; February, (1933).

A brief description of lighting control, sound, and air conditioning applications of vacuum tubes.

621.383.21 Relays for electronic devices. *Electronics*, vol. 6, pp. 36–38; February, (1933).

A brief description is given of some types of relays now available. They are grouped into: Supersensitive relays using less than 0.5 milliampere; telephone relays using one or more milliamperes, and auxiliary relays using large currents. A table is given in which are listed the characteristics of a group of relays. A list of relay manufacturers is also given.

CONTRIBUTORS TO THIS ISSUE

Aiken, Charles B.: Born October 6, 1902, at New Orleans, Louisiana. Marine radio operator, summers, 1918–1921. Received B.S. degree in physics, Tulane University, 1923; M.S. degree, Harvard, 1924; M.A. degree, Harvard, 1925. Winner of Harvard Engineering School Prize Scholarship for 1923–1294; Whiting Fellow in Physics, 1924–1926. Research engineer, Mason, Slichter and Hay, Consulting Engineers, 1926–1928. Engineer, radio development department, Bell Telephone Laboratories, 1928 to date; engaged in aircraft communication development, 1928–1929; broadcast receiver work, 1929 to date; supervisor, broadcast receiver development, Bell Telephone Laboratories. Associate member, Institute of Radio Engineers, 1925.

Kenrick, G. W.: Born May 25, 1901, at Brockton, Massachusetts. Received B.S. degree in physics, Massachusetts Institute of Technology, 1922; M.S. in physics, M.I.T., 1922; Sc.D. in Mathematics, M.I.T., 1927. Department of Physics, M.I.T., 1920–1922; department of development and research, American Telephone and Telegraph Company, 1922–1923; instructor in electrical engineering, M.I.T., 1923–1927; Moore School of Electrical Engineering, University of Pennsylvania, 1927–1929; assistant professor of electrical engineering, Tufts College, 1929 to date; consulting radio engineer, Bureau of Standards, 1930 to date. Associate member, Institute of Radio Engineers, 1923; Member, 1929.

Lyons, Walter: Born October 5, 1906, at New York City. Received B.Sc. degree in electrical engineering, McGill University, 1928; M.Sc. in physics, McGill University, 1932. Attended Columbia University, 1929–1930. Radio amateur, 1919 to date. Engineer, Victor Talking Machine Company of Canada, 1928; research department, Western Union Telegraph Company, 1928–1929; plant engineer, Balkeit Radio Company; receiver engineer, Universal Wireless Company, 1929; engineer, Hazeltine Service Corporation, 1929–1931; graduate student and demonstrator in physics, McGill University, 1930–1932; engineer, Wells-Gardner and Company, 1932 to date. Associate member, Sigma Xi, 1930, student member, Engineering Institute of Canada, 1928. Associate member, Institute of Radio Engineers, 1929.

Martin, John R.: Born June 16, 1897, at Jacksonville, Illinois. Received B.S. degree, Illinois College, 1920; M.S. degree, Case School of Applied Science, 1926. Instructor, Signal Corps Schools, U. S. Army, 1917–1919. Instructor in Physics, 1920–1926; assistant professor of research physics, 1926–1931; assistant professor of electrical communications, Case School of Applied Science, 1931 to date. Member, American Physical Society; Member, American Association for the Advancement of Science. Nonmember, Institute of Radio Engineers.

McCuskey, Sidney W.: Born February 28, 1907, at Cuyahoga Falls, Ohio. Received B.S. degree, Case School of Applied Science, 1929; M.S. degree, Mas-

sachusetts Institute of Technology, 1930. Amateur radio, 1925 to date. Instructor in mathematics and Astronomy, Case School of Applied Science, 1930. Member, American Association for the Advancement of Science; Member, American Astronomical Society. Nonmember, Institute of Radio Engineers.

Mimno, Harry Rowe: Born May 8, 1900, at Chicago, Illinois. Graduated, electrical engineering department, Rensselaer Polytechnic Institute, 1921. Instructor, Rensselaer, 1921–1925. Graduate student, department of physics, Harvard University, 1925–1928. Assistant professor of physics and electrical engineering, Rensselaer Polytechnic Institute, 1928–1929. Instructor in physics and communication engineering, Harvard University, 1932 to date. Reserve officer, U. S. Signal Corps. Member, Sigma Xi, American Physical Society, Acoustical Society of America, American Institute of Electrical Engineers, American Association for the Advancement of Science. Associate member, Institute of Radio Engineers, 1931.

Thompson, B. J.: Born 1903 at Roanoke, Louisiana. Received B.S. degree in electrical engineering, University of Washington, 1925. Research laboratory, General Electric Company, 1926–1930; vacuum tube engineering department, 1930 to June, 1931. In charge, electrical research section, research and development laboratory, RCA Radiotron Company, Inc., 1931 to date. Associate member, Institute of Radio Engineers, 1929; Member, 1932.

Wang, P. H.: Born 1902 at Shentze, Hopei, China. Received B.S. degree, Yenching University, 1924; M.S. degree, Harvard University, 1931. Instructor, Peking Academy, 1925–1929; Peiping University, 1929–1930. Student, Harvard University, 1930 to date. Nonmember, Institute of Radio Engineers.